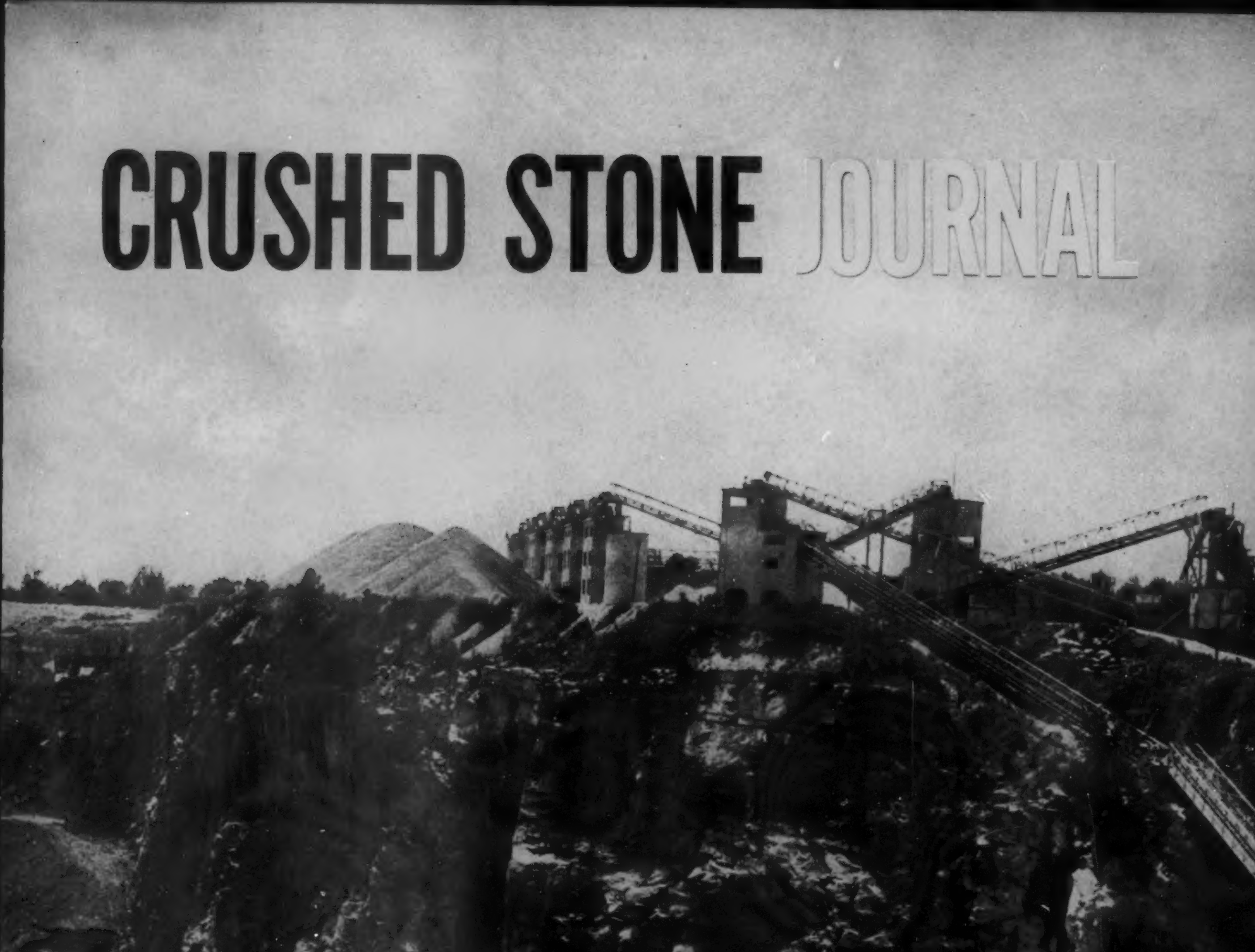
CRUSHED STONE JOURNAL



SEPTEMBER 1961

OFFICIAL PUBLICATION OF THE NATIONAL CRUSHED STONE ASSOCIATION

45th ANNUAL CONVENTION

NATIONAL CRUSHED STONE ASSOCIATION

MANUFACTURERS EXPOSITION

KEY YOUR PLANS NOW TO ATTEND

MONDAY

Morning — General Session
Noon — Greeting Luncheon
Afternoon — Inspection of Manufacturers Exposition
Evening — Social Hour
— Open for Individual Plans

TUESDAY

Morning — Session for Operating Men and Equipment Manufacturers
Noon — Concurrent Luncheon Sessions
Company Executives
Manufacturers Division
Afternoon — General Session
Evening — Open for Individual Plans

WEDNESDAY

Morning — Inspection of Manufacturers Exposition
Noon — General Luncheon
Afternoon — General Session
Evening — NCSA Party
Dinner-Entertainment-Dancing

FEBRUARY 12, 13, 14, 1962 · CONRAD HILTON · CHICAGO, ILLINOIS

Crushed Stone Journal

Official Publication of the NATIONAL CRUSHED STONE ASSOCIATION

VOL. XXXVI No. 3 PUBLISHED QUARTERLY September 1961

NATIONAL CRUSHED STONE ASSOCIATION

1415 Elliot Place, N. W.
Washington 7, D. C.

Contents

Cover Photograph—Columbia Quarry, Palmetto Quarries Company, Columbia, South Carolina

Congratulations

TO THE WINNERS OF THE

1960

NATIONAL CRUSHED STONE ASSOCIATION

Safety Contest

A RECORD NUMBER OF

65

SAFETY AWARDS

WILL BE PRESENTED TO REPRESENTATIVES OF

TWENTY-SEVEN MEMBER COMPANIES

OF THE

NATIONAL CRUSHED STONE ASSOCIATION

AT ITS 45TH ANNUAL CONVENTION

FEBRUARY 12, 1962

THE CONRAD HILTON, CHICAGO, ILLINOIS

APPRECIATION IS EXPRESSED TO THOSE INDUSTRY MEMBERS WHO PARTICIPATED IN MAKING THE 1960 CONTEST YEAR ONE OF THE MOST SUCCESSFUL IN THE 35 YEAR HISTORY OF THE COMPETITION

The Effect of Shape of Particle on Properties of Air Entrained Stone Sand Mortar

J. E. Gray

Engineering Director
National Crushed Stone Association
Washington, D. C.

THE results of an investigation of the effect of shape of particle on non-air entrained mortar were reported by A. T. Goldbeck in the June 1951 issue of the Crushed Stone Journal which concluded with the statement that "Certainly the evidence is clearly in favor of a low void content, indicative of cubical particle shape, for producing good workability in concrete. A percentage of voids of, say, 52 is desirable, and 51 is still better; 53 is on the borderline of acceptability."

The term "low void content" referred to an indirect method of measuring shape of particle by determining the average void content of sand separated into size fractions of No. 8-16, No. 16-30, and No. 30-50 in a method of test which is given in the appendix. The principle is that flat particles, falling freely in a container, will have a high void content and rounded particles will have a low void content; consequently, the per cent voids may be used to describe the degree of cubicity of fine aggregate.

Now, the question arises: If air entrainment improves the workability and durability of mortar as much as reputed, should the suggested limit on shape of particle of stone sand be revised? The following investigation was made in an effort to establish data to aid in answering this question.

Since the primary use of stone sand is for fine aggregate in structural concrete it was decided that the purpose of this study could be accomplished by investigating the properties of stone sand mortar made in proportions approaching the mortar fraction in the most commonly used concrete mix. This concrete mix is believed to have a cement factor of 5 bags which calculated to have a cement to sand ratio of 1 to 2 3/4 by weight. Consequently all mixes were of the proportions of 1 part cement to 2 3/4 parts sand with an optimum entrained air content of 9 ± 1 per cent and a constant consistency or flow of 110 ± 5.

The parent rock was a good grade of limestone from which stone sand was obtained with four different shapes of particle which may be described as follows:

Voids, per cent	Description
55	Gradings prepared in laboratory from stone screenings by dry sieving
53	Stone sand from commercial production
51	Stone sand from commercial production
49	Stone sand put through laboratory grinding mill to round off edges and give particle shape approaching natural sand

Gradations

Five gradings were made with each of the four stone sands of different degrees of flatness of particle which gradings were considered sufficient to encompass the range in practical use and are given in Table I.

TABLE I
GRADATION OF STONE SAND

Identification *	F	MF	M	MC	C
Sieve Size	Total per cent passing				
No. 4	100	100	100	100	100
No. 8	95	92	90	88	85
No. 16	80	75	70	65	60
No. 30	50	45	40	35	30
No. 50	25	22	20	18	15
No. 100	10	8	7	6	4
Fineness Modulus	2.41	2.58	2.73	2.88	3.06

* *Abbreviations:* F—fine; M—medium; C—coarse

Dry-rodded unit weight determinations were made on the sands for each particle shape and for each of the five different gradations and the per cent voids in these graded sands were then computed as shown in Table II.

It is interesting to observe in Table II that the shape of particle has a much greater influence on the per cent voids than the range in gradations;

TABLE II
PER CENT VOIDS IN GRADED DRY-RODDED SAND

Identification	F	MF	M	MC	C
Fineness Modulus	2.41	2.58	2.73	2.88	3.06
NCSA Particle Shape Test (per cent voids)	Voids, per cent				
49	33.9	34.1	34.0	34.0	34.7
51	35.7	35.7	35.7	35.4	36.3
53	37.1	37.3	37.1	36.7	37.3
55	38.1	38.2	37.7	37.8	38.7

thus, the difference in voids from the fine grading to the coarse grading is only 0.6 per cent on the average while the difference due to shape of particle is 4.0 per cent on the average.

Tests on Fresh Mortar

Type I portland cement was used in the proportions of 1 part cement to 2 3/4 parts sand by weight. Diluted Vinsol resin solution was used as the air entraining agent to obtain 9 ± 1 per cent air in the mortar batches as determined by the volumetric method described in ASTM Designation C 91-58. The amount of mixing water was such as to produce a flow of 110 ± 5 per cent as determined in accordance with ASTM Designation C 109-58.

The freshly mixed mortar was tested for air content, unit weight, flow, and flow after suction. Flow after suction, or water retentivity test as it is better known, is used for testing masonry mortars but was used in this investigation as a forced bleeding test to possibly aid in evaluating the various sands with respect to workability. From each batch of mortar, 2 in. cubes were molded for compressive strength tests after 28 days of curing in water under standard conditions. Also, 2 by 2 by 10 in. beams were molded for freezing and thawing tests.

Tests on Hardened Mortar

Two methods of curing the beams prior to freeze-thaw exposure were used—one method consisted of 28 days moist curing while the other consisted of 14 days moist curing, air drying for 14 days (room temperature with a relative humidity of approximately 50 per cent), followed by 7 days water immersion before starting the freeze-thaw exposure. Thus cured, the beams were subjected to rapid freezing in air at 0 F and thawing in water at 40 F (ASTM Designation C 291-57T). Transverse frequency readings were made on the beams at appropriate intervals and reported in terms of durability factor using a minimum relative dynamic modulus of 60 per cent to indicate failure, and 300 as the maximum number of freeze-thaw cycles.

Discussion

The test data are given in Table III which includes the batch weights, properties of the fresh mortar, compressive strength, resistance to freezing and thawing, as well as calculated water-cement and water plus air-cement ratios. In Figure 1 are shown graphically the most significant relationships of shape of particle and gradation to the properties of the mortar. The results of each test are plotted and lines are drawn for each variable which indicates only the general trend. The test results as given in Figure 1 will be discussed in some detail.

First, all of the mixes were durable; that is, they were well above the limitations as given, even for those specimens which were continuously wet. The advantages of a period of air drying before freezing did not show up in these tests because all specimens possessed excellent resistance to freezing and thawing. Of course, this is essentially a verification of the recommendations of ACI Committee 613 that the optimum air content is about 9 per cent in the mortar portion of concrete. Thus, it is indicated that the shape of particle of stone sand has little effect on the durability of the mortar provided that the mortar has the optimum amount of entrained air.

The test on water retention furnishes some interesting and helpful data in evaluating these various stone sands. Not only does stone sand with a large amount of flat or elongated particles require more water for a given consistency than stone sand with good particle shape, but also it more readily gives up this water or has a tendency to bleed which can result in poor workability. However, gradation is important in affecting the amount of bleeding that may occur. Except for the most rounded stone sand it seems as though a gradation with a fineness modulus much above 3.0 may be the cause of excessive bleeding and, under some conditions, a lack of workability.

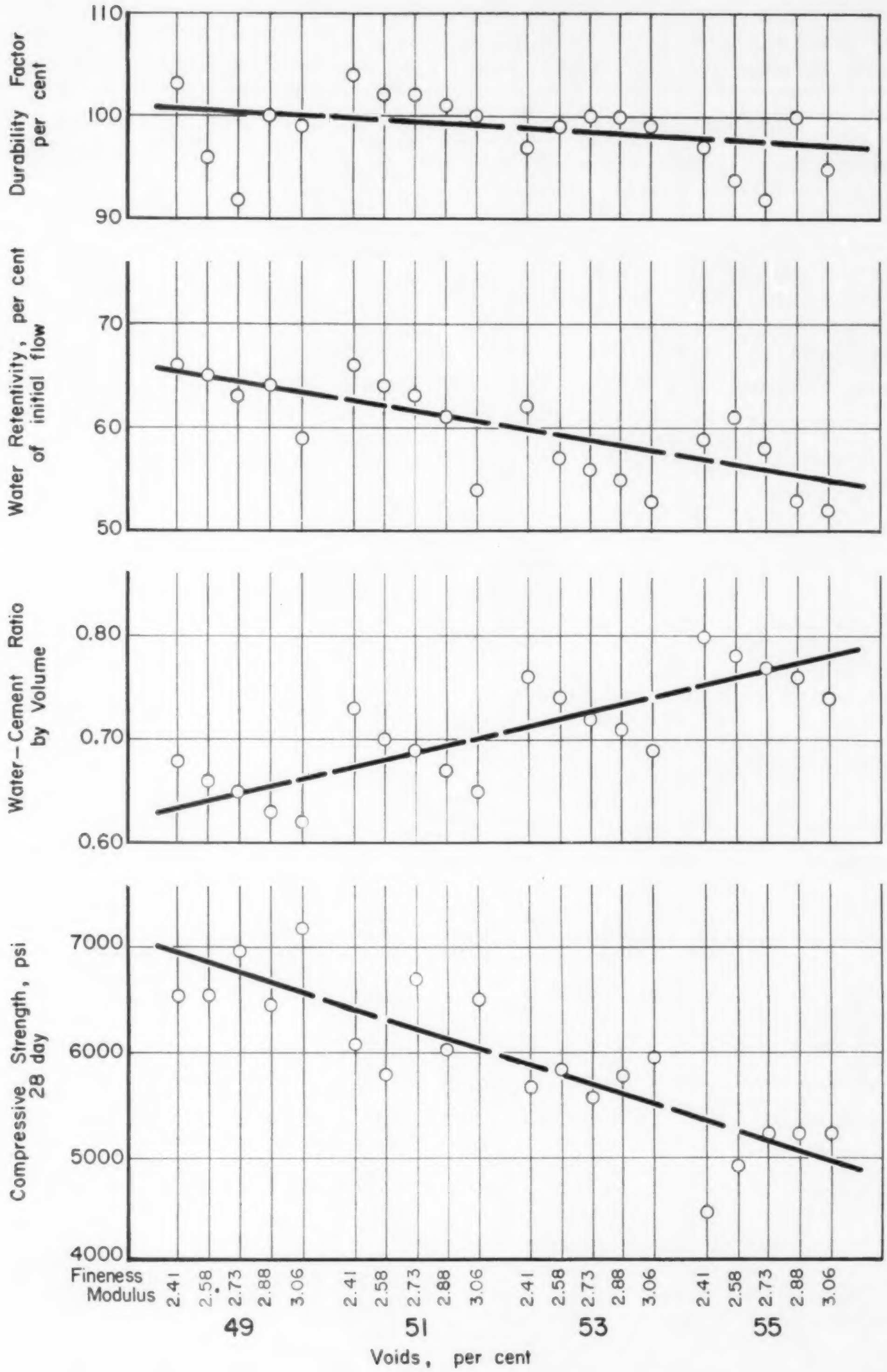


FIGURE 1

Influence of Particle Shape and Gradation on Properties of Air Entrained Concrete Mortar

TABLE III

SUMMARY OF RESULTS

All mixes were proportioned by weight: 1 part cement to 2 3/4 parts stone sand

Particle Shape (per cent voids)	49					51				
Mix Identification	Fine	Medium Fine	Medium	Medium Coarse	Coarse	Fine	Medium Fine	Medium	Medium Coarse	Coarse
Fineness Modulus	2.41	2.58	2.73	2.88	3.06	2.41	2.58	2.73	2.88	3.06
Batch Weight										
Water, gm	410	399	394	384	376	441	426	415	406	395
Cement, gm	909	909	909	912	911	910	911	909	910	909
Sand, gm	2500	2500	2500	2509	2506	2502	2505	2501	2503	2500
Mortar Properties										
Air content, per cent	9.7	8.9	9.6	9.9	9.6	9.4	9.7	8.7	9.5	9.3
Density-solid volume, per cent (sand & cement)	68.2	68.5	68.2	68.4	69.2	66.5	67.9	68.0	68.6	68.4
Flow, per cent	113	112	111	111	106	112	107	106	112	109
Water retention, per cent	66	65	63	64	59	66	64	63	61	54
Compressive Strength, psi	6530	6530	6960	6450	7180	6070	5780	6700	6010	6500
Durability Factor, per cent										
A—Moist cured 28 days	103	96	92	100	99	104	102	102	101	100
B—Moist cured, 14 days, air dried 14 days, immersed 7 days	104	99	103	102	102	103	103	102	100	102
Volume Ratios										
Water plus air to cement	2.03	1.94	1.95	1.95	1.87	2.11	2.13	2.01	2.03	1.95
Water to cement, solid vol.	1.43	1.39	1.37	1.33	1.31	1.54	1.48	1.45	1.41	1.38
Water to cement, bulk vol.	.68	.66	.65	.63	.62	.73	.70	.69	.67	.65
Weight Ratio										
Water to cement	.45	.44	.43	.42	.41	.48	.47	.47	.45	.43

Particle Shape (per cent voids)	53					55				
Mix Identification	Fine	Medium Fine	Medium	Medium Coarse	Coarse	Fine	Medium Fine	Medium	Medium Coarse	Coarse
Fineness Modulus	2.41	2.58	2.73	2.88	3.06	2.41	2.58	2.73	2.88	3.06
Batch Weight										
Water, gm	459	444	435	427	416	486	474	467	458	447
Cement, gm	909	910	910	910	910	913	909	910	911	909
Sand, gm	2500	2503	2502	2502	2503	2512	2500	2502	2505	2501
Mortar Properties										
Air content, per cent	9.1	8.4	9.0	9.2	9.3	9.0	8.9	8.7	8.9	9.5
Density-solid volume, per cent (sand & cement)	66.0	67.2	67.1	67.3	67.7	65.2	65.6	66.0	66.3	66.3
Flow, per cent	112	110	112	113	110	111	108	113	112	114
Water retention, per cent	62	57	56	55	53	59	61	58	53	52
Compressive Strength, psi	5660	5820	5560	5760	5940	4480	4920	5220	5220	5230
Durability Factor, per cent										
A—Moist cured 28 days	97	99	100	100	99	97	94	92	100	95
B—Moist cured, 14 days, air dried 14 days, immersed 7 days	103	97	97	102	103	103	97	95	97	103
Volume Ratios										
Water plus air to cement	2.18	2.09	2.13	2.08	2.04	2.32	2.25	2.19	2.17	2.18
Water to cement, solid vol.	1.60	1.55	1.52	1.49	1.45	1.69	1.65	1.63	1.59	1.56
Water to cement, bulk vol.	.76	.74	.72	.71	.69	.80	.78	.77	.76	.74
Weight Ratio										
Water to cement	.50	.49	.48	.47	.46	.53	.52	.51	.50	.49

The water-cement ratio data shows that shape of particle has a greater influence on the water requirements for a given consistency than the gradation. While fine graded sand requires more water than coarse graded sand, poorly shaped sand requires an excessive amount of water in comparison with a sand that has good particle shape.

Of course, the water-cement ratio controls the strength. As the water-cement ratio increases, the strength decreases. While no sharp break occurs in the trend lines, there is no doubt that stone sand with excessive amounts of flat and elongated pieces should be used only when provision is made to use additional cement in order to reduce the water-cement ratio and thereby increase the strength and improve workability. The results of these tests may be considered as a reaffirmation of the earlier series of tests referred to in the beginning which concluded that "53 per cent voids is on the borderline of acceptability."

Conclusions

Stone sand is being produced and successfully used which has a 53 per cent void content. This suggested limit on shape of particle of 53 per cent has merit in two respects: first, it practically prohibits the use of screenings which are almost invariably of poor particle shape and without any control on gradation; and secondly, it assures a stone sand of reasonably good shape which must be a processed material and consequently has a controlled gradation.

The proposed method of test for shape of particle appears after Table III.

Proposed Method of Test for Voids in Individual Size Fractions of Manufactured Stone Sand Fine Aggregate for Concrete

Scope

1. This method of test describes a procedure for determining voids in individual size fractions of stone sand fine aggregate. It is intended that the voids so determined be used as an indirect measure of the shape of the sand particles.

Apparatus

2. *(a) Balance.*—A balance having a capacity of 1500 g or more and sensitive to 0.1 g or less.

(b) Containers.—Metal pans of at least 1500 g capacity suitable for drying samples.

(c) Cylinder.—A cylindrical tube having an inside diameter of 2 7/8 in. and a height of 5 1/2 in. mounted on a metal base. Thickness of base and cylinder wall should be sufficient to withstand normal use without distortion.

(d) Cone.—A truncated metal cone having an overall height of 4 in., inside diameters of 5 1/2 in. for the large opening and 1 in. for the small opening. The truncated cone shall be mounted with the small diameter downward on a suitable frame so that when performing the test the axis of the cone and cylinder are on the same vertical line. The plane of the small end of the cone shall be exactly 1 in. above the top plane of the cylinder.

(e) Sieves.—Sieves with square openings conforming to Specifications for Sieves for Testing Purposes (ASTM Designation D 11) of the following sizes are required:

No. 8, No. 16, No. 30, No. 50

(f) Straight Edge.—A steel straight edge 1 by 6 by 1/16 in. thick.

Samples

3. *(a) Fine Aggregate.*—Samples of fine aggregate for test shall be obtained by the method of quartering or by use of a sample splitter.

The sample shall be washed thoroughly, dried to constant weight at 105 to 110 C (221 to 230 F), and separated into the following sizes:

Passing	Retained on
No. 8	No. 16
No. 16	No. 30
No. 30	No. 50

Approximately 1500 g of each of the above sizes is required for test.

(b) Coarse Aggregate.—A sample of coarse aggregate is required for specific gravity determination. This sample shall consist of 5000 g of material which passes the 1 1/2 in. sieve and is retained on the 3/4 in. sieve, and shall be representative of the material from which the fine aggregate sample is derived.

Procedure

4. *(a)* The apparatus shall be assembled as indicated in 2*(d)* on a flat rigid surface free from vibration.

(b) One of three sizes of fine aggregate to be tested shall be poured into the cone while a stiff piece of metal is held against the bottom aperture. The cone shall be filled until the sand is heaped above the top level of the cone between one and two in., care being taken not to overflow the cone or spill material into the cylinder below. The piece of metal used to close the bottom of the cone is quickly withdrawn in a horizontal

movement and the sand permitted to flow freely into the cylinder beneath until it overflows. The flow of sand from cone to cylinder is then cut off and any sand remaining in the cone is allowed to flow into a shallow pan.

(c) The cylinder shall then be carefully struck off with the straight edge, level with the top of the cylinder. This is accomplished by holding the straight edge in both hands, edge down; starting at one side, strike off the sand above the plane of the cylinder. The straight edge is then placed along a diameter of the cylinder and the sand struck off again. This is then repeated in the opposite direction.

Extreme care should be taken during the striking off operation to avoid any downward pressure on the sand or any jarring of the cylinder.

(d) The weight of the contents shall be determined to the nearest 0.1 g.

(e) The sand shall then be recombined with the excess from the cone, thoroughly mixed, and two additional determinations made. An average of three determinations having a maximum range of 4 g shall constitute a test.

(f) Tests shall be performed on each size separately.

Calculations

5. The per cent voids of each size shall be determined by the following formula:

$$\text{Per cent voids} = 100\left(1 - \frac{W}{VG}\right)$$

W = weight of sand in cylinder

V = volume of cylinder in cubic centimeters

G = bulk specific gravity of the coarse aggregate as determined by the applicable portions of ASTM Designation C 127-42

NOTE.—When a highly porous or vesicular material is brought to a saturated surface dry condition, some of the water in the surface voids drains or evaporates from the individual sand particles, thereby indicating a lower bulk volume and consequently a higher bulk specific gravity than would be obtained should the surface voids remain filled with water. By using coarse aggregate approximately one inch in size in determining the bulk specific gravity, this effect of surface voids is minimized due to the relatively small surface area exposed. Therefore, it is desirable that the bulk specific gravity of coarse aggregate be used in the preceding formula.

Report

6. The per cent voids obtained from the arithmetical average of the per cent voids of the three sizes tested shall be reported./NCSA

Lafayette C. Mosley
1893-1961

IT IS with a heart full of sorrow and a sense of personal loss that we announce the death of Lafayette C. Mosley on August 28, 1961. The end came in Cleveland, following surgery to correct an enlarged aorta. When told that he could live on as a partial invalid or risk an operation with a 50-50 chance of success, he characteristically said that he would take the risk even if his chances were only 20-80.

"Mose," as he was lovingly known in the quarrying and mining field, joined the Marion Power Shovel Company in 1925, and from 1946 until the time of his death was Manager of the Mining Division. During his career he dealt primarily with the application of shovels and draglines to specific mining problems. Not only was his judgment and integrity highly respected, but the warmth of his personality and his delightful sense of humor were ever present.

The National Crushed Stone Association, and its Manufacturers Division in particular, owe much to Mose for his loyalty and devotion of many years standing. Mose thoroughly enjoyed meeting his host of friends at the Annual Conventions of the National Crushed Stone Association, and could always be counted on for a good story told in his inimitable fashion. He served on the Board

(Continued on page 23)

$3 Billion of Federal Aid Highway Funds Apportioned For Fiscal Year 1963

SECRETARY of Commerce Luther H. Hodges, at the direction of the President, has apportioned $3.1 billion of federal aid to the states for fiscal year 1963 to continue the expanded national highway program.

The new apportionment includes $2.4 billion for the interstate system, the full amount authorized for fiscal year 1963 by the 1961 Act. This is $200 million more than the original authorization by previous legislation. With one exception, it is the largest apportionment made to date for the interstate system.

The 41,000 mile interstate system, for which the federal government is paying 90 per cent of the cost, is the backbone of the nation's highway transportation network. Designed to handle adequately and safely the traffic anticipated in 1975, these controlled access superhighways, which comprise little more than 1 per cent of the total U. S. mileage of roads and streets, will carry over 20 per cent of all traffic in the United States. By 1975 there will be well over 100 million motor vehicles in this country, traveling more than a trillion miles a year. In addition to great benefits to motorists and truckers and to economic development along its routes, the interstate system is expected to save at least 4,000 lives a year.

The Interstate funds are apportioned, as provided by law, in the ratio that the estimated cost of completing the system mileage in each state bears to the total estimated cost of completing the entire system. The estimates used in making the 1963 apportionment are those reported to the Congress in January 1961, which indicated that completion of the system would cost about $41 billion. This estimate agreed closely with that made in 1958.

$693,750,000 Apportioned for ABC Program

The new apportionment for the regular or so-called ABC federal aid program for the fiscal year 1963 totals $693,750,000. In this program, the states match the federal grants on a 50-50 basis.

While the full amount authorized by the 1960 Act for fiscal year 1963 is $925 million, 25 per cent of the total has been withheld temporarily, pending availability from the Post Office Department of the June 30, 1961, post road mileage (rural delivery and star routes). Post road mileage is one of the elements involved in the apportioning of federal aid primary and secondary funds among the states. When the required data become available, a revised ABC fund apportionment will be made, covering the full $925 million authorized. For the 75 per cent of the authorization now being apportioned, last year's post road mileage data were used in the calculations.

The present ABC fund apportionment includes $312,187,500 for the federal aid primary system which, including the interstate system, comprises almost all main routes of travel in the United States and is 265,000 miles in length. Also included in the current apportionment are $208,125,000 for the 590,000 mile federal aid secondary system of farm-to-market and feeder roads, and $173,437,500 for the urban portions of the federal aid primary and secondary systems.

The ABC funds are apportioned among the states according to formulas established in the federal aid legislation, which take into account the relative population, area, and post road mileage in each state.

Adjustment of ABC Apportionment

After calculation of the apportionment, according to the prescribed formulas, of the $693,750,000 of the 1963 ABC funds now being allocated among the states, adjustments were necessary for two reasons, both related to apportionments made in prior years.

The final apportionment of fiscal year 1962 ABC funds, announced by Secretary Hodges on January 4 of this year, was made on the basis of supposedly final 1960 census data. However, revised data on rural and urban population in places of 5,000 or more have now become available. Adjustments to rectify the 1962 ABC apportionment accordingly have been made in the new apportionment for 1963.

In addition, the Comptroller General of the

(Continued on page 24)

Studies of Blasting Near Buildings*

A. T. Edwards

Structural Research
The Hydro-Electric Power Commission of Ontario
Toronto, Canada

Dr. T. D. Northwood

Division of Building Research
National Research Council of Canada
Ottawa, Canada

PROBLEMS associated with possible damage to nearby buildings are some of the more vexing aspects of blasting operations. For instance, much construction work is hampered by the necessity of preventing ground transmitted shock from exceeding a rather indefinitely established "safe limit." Another problem is that of evaluating damage claimed by building owners to have been caused by blasting. In order to establish the validity of such claims, a critical study is necessary of the details of the blasting operations that occurred.

Various criteria have been proposed for the control of blasting so as to prevent damage, of which the best known are those of Thoenen and Windes,[1] Crandell,[2] and Morris.[3] Unfortunately their applicability to the problem has been difficult to judge since very few instances of accurate observations of blasting operations and of the resulting damage to buildings have been reported. Clearly the only way to obtain the necessary data is to conduct controlled blasting with the object of producing damage to buildings.

The St. Lawrence Power Project provided an opportunity for such an experiment. Permission was obtained for studies on a few of the buildings soon to be demolished because they stood on land which would be inundated by head pond water. The selected buildings were both of frame and of brick construction, and had basements with walls of heavy stone masonry. Although old, all were in good condition.

The selection was based on a consideration of the characteristics not only of the houses, but also of the local soils. Soils of two types were present: one a rather soft sand clay material and the other a well consolidated glacial till. Although rock occurred in the head pond area, unfortunately none of the buildings was founded on rock. After the experimental work was done, however, a paper appeared describing blasting studies in Sweden by Langefors, Westerberg and Kihlstrom[4] on buildings founded on rock. The St. Lawrence and the Swedish studies together provide blasting damage information for a wide range of soil conditions.

In addition to the establishment of damage criteria, a further aim of the present study was the evaluation of methods for the control of blasting operations. A criterion based simply on explosive charges and distances must necessarily be conservative, since allowance must be made for variations in terrain. Moreover, many special conditions may be encountered, such as the need for multiple charges and the presence of unusually complicated structural features in a building, either of which would make the formulation of precise damage criteria impossible. If actual measurements of vibration due to blasting could be made, however, the use of larger charges might be feasible. Hence a reasonably simple technique for obtaining vibration values that will provide dependable blasting criteria of damage risk would be desirable. The uncertainty of present blasting knowledge is illustrated by the fact that the existing criteria are based respectively on maximum acceleration, velocity, and displacement. Which of these is the most useful quantity, and how do they differ? In this article are described the different items of equipment used for measuring and recording vibration data, their installation, the blasting procedures followed, the damage sustained by the buildings, and the relations of damage to the values obtained of acceleration, velocity, and displacement. Other special measurements made, including those of strain in building walls, are also described.

Occasionally some damage (usually broken windows) is caused by air blast. In the St. Lawrence studies air blast pressures were controlled to insure that all damage caused was due to ground transmitted vibration.

* Reprinted from Ontario Hydro Research News, Toronto, Canada—Vol. 13, No. 1, January-March 1961; Condensed from original paper printed in the Engineer—September 30, 1960. Reprinted with permission

Soil Conditions and Building Features

The six buildings selected stood on soil of two different types, as previously mentioned. Three of the buildings were on loose wet sand about 20 ft deep overlying soft marine clay. The soil density was of the order of 110 lb per cu ft. During the tests the water table was about 7 ft below grade. In this article this soil will be referred to as *sand clay*. The remaining buildings stood on glacial till, referred to hereafter as *till*, a high shear strength material consisting of a densely compacted mixture of sand, clay, gravel, and boulders. The density of this material was about 145 lb per cu ft, and the water content about 10 per cent. Both soils were frozen to a depth of about 1 ft at the time of the tests.

FIGURE 1
A 2 Story Brick Building Typical of Those Used in the Tests

The buildings are briefly described and designated in Table I. Figures 1 and 2 are photographs of a brick and a frame building respectively, typical of those selected. All were in good condition except that the bond between the bricks and the mortar in two of the buildings was weak. The house shown in Figure 1 had a 45 degree patched crack across the front wall; the crack was said to have been caused by the Cornwall earthquake of 1945.

Instrumentation

The instruments used for the measurement and recording of vibration quantities are discussed in the following groups:

SHOCK MEASURING INSTRUMENTS

Seismographs: One Sprengnether and three modified Leet three component seismographs were used to measure displacement. Each Leet instrument has a nominal magnification of 50, being thereby capable of providing useful records of displacements of from about 0.001 to 0.025 in. The Sprengnether has a magnification of 320 in the vertical and 180 in the horizontal direction. It can record displacements of from about 0.0001 to 0.005 in.

Seismometer: Two Willmore-Watt seismometers were used to measure the velocities of the movements of the structure and of the ground. Although these seismometers are single component instruments, a simple adjustment permits measurements of velocity in either the vertical or the horizontal direction. In the present study, however, motion in only the horizontal direction longitudinal to the blasting was measured.

Accelerometer: An accelerometer is also a seismic device but with a natural frequency beyond the range of blasting frequencies studied. The natural frequencies of three transducers used are each of the order of 400 cycles per second, those of two are 250 cycles each, and that of one is 110 cycles. The frequency response of the recording system is flat for frequencies well beyond the useful range of the accelerometers used.

FIGURE 2
The 2 Story Frame Building Used in the Tests

Certain requirements are necessary to insure that all shock measuring instruments will give true indications of blasting vibration. The first requirement is that they be fastened securely both to the building and to the medium (earth) in the vicinity of blasting operations. Without secure

fastening, vertical components of acceleration greater than that due to gravity (g), or considerably smaller horizontal components, will cause relative movement between the medium or building and the transducers. A second requirement is that the instrument should not be of a weight that will load the medium significantly. Consequently the rather heavy seismographs available were anchored on extensive rigid surfaces such as basement floors or paved roads.

Recording Equipment

Oscillographs: The recorders used in conjunction with the instruments described are a photographic type multi-channel oscillograph and a direct-writing oscillograph. The respective responses of the amplifiers and galvanometers associated with the recorders are flat from 0 to 600 cycles, and that of the galvanometer connected directly to the seismometer is flat to 1,000 cycles per second. The response of the direct-reading oscillograph is approximately flat from 0 to 100 cycles per second.

Ancillary Measuring Devices

Strain Gauges: An attempt was made to measure the dynamic strain in the walls of the buildings, due to blasting. The nonhomogeneity of the wall, however, made impractical the application of resistance wire strain gauges in the usual manner. Therefore a method was devised for measuring the total strain along the entire length of a wall by means of resistance wire strain gauges attached to thin steel strapping secured at diagonally opposite corners of a wall. By subjecting the strapping, before the gauges were affixed, to a tension equal to about half its yield strength, both negative and positive strains to the elastic limit of the strapping could be measured.

Microphone Oscillograph Circuit: Since the differentiation of possible damage by air blast from damage by ground transmitted shock was desirable for the study, a suitable system was installed for monitoring air blast pressures. For this purpose a simple crystal microphone was used in conjunction with a cathode ray oscillograph, the resulting signal image, representing the air blast pressure, being photographed.

Falling Pin Gauges: The opportunity was taken of correlating the response of falling pin gauges both with damage and with ground vibration. The gauges used comprised eight 1/4 in. diameter rods ranging from 6 to 15 in. in length. These were stood on end on a carefully levelled flat plate. Provision was made to prevent falling pins from disturbing the remainder.

TABLE I

Details of Buildings Selected for Test

Building Designation	Building	Superstructure (Walls) Outside	Inside	Approx. Dimensions (ft) Length	Width	Wall Ht.
On sand clay						
C	Church	Brick, 12 in. thick	Plaster	51	31	13
E	House	Brick, 12 in. thick	Plaster	43	37 (front) 16 (back)	16
S	School	Brick, 12 in. thick	Plaster	74	28	25
On till						
R	House	Frame and wood siding	Wood-fibre board	23	29	15
T	House	Brick, 12 in. thick	Plaster	51	30	20
F	House					
	Main	Brick, 12 in. thick	Plaster	55	24	17
	Annex	Frame and wood siding	Plaster			

NOTES: All building basement walls were of stone and mortar, 18 to 24 in. thick
The wood frame house was about 18 years old; each of the others was at least 50 years old
All buildings except the church had a second story

Building Damage Indication

In addition to the arrangements necessary for measuring and recording vibration, provisions were made for the indication and assessment of building damage. The elements of damage indication and the procedures for observing these elements were as follows:

Cracks: In order to obtain positive indications of movements affecting existing cracks in plaster or in basement walls, a sheet of paper (tell-tale) was pasted across each crack (see Figure 3). The adhesive used was one that dries rigid, to ensure that a widening or an extension of a crack would produce a tear in the paper.

Settlement: Excessive settlement of a structure, which rather than the building vibration could be the primary cause of damage, was measured with a precision level. Reference points were set up, usually in the basements of the buildings concerned, and wherever possible, a reference datum remote from the test site was also established. Settlement was determined from measurements made, both before and after each blast, of the levels of the reference points and the datum.

Building Misalignment: Plumb bobs were suspended immediately above reference points at ground level, by lines attached to points near the top of each building. These plumb lines were used to record permanent movement of the top of the building relative to the ground.

Typical Test Procedure

Preparatory and post blasting procedures were as follows:

Each building was carefully examined, all portions of the structure in poor condition being appropriately marked and noted. Telltales were pasted over cracks. Photographs were taken, before blasting, of areas where damage was expected, and again of the same areas after blasting.

Plumb lines were installed, and reference points set up for settlement measurements.

Accelerometers, seismometers, seismographs, falling pin gauges, and the strain measuring equipment were installed and connected to the various respective recording devices. The air blast monitoring equipment was arranged outside the buildings. Seismographs were also suitably disposed at two or three distant locations for monitoring the larger blasts.

The blasting procedure consisted of the detonation of charges of increasing intensity until the buildings were damaged. The ground vibration and the movements of the buildings were observed for each charge and the buildings were carefully examined for signs of visible damage.

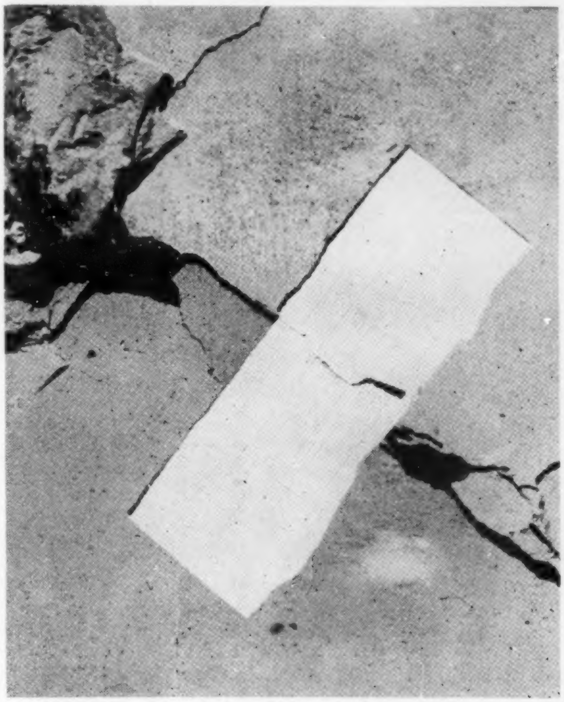


FIGURE 3
A Paper Tell-Tale Pasted Across a Crack

Arrangements for acceleration measurements were straightforward. Accelerometers were usually fastened securely to the buildings' foundation walls nearest to the blast source, with additional units at other appropriate points throughout the buildings. Adjustment of the gains of the associated amplifiers to obtain records of suitable amplitude were the only alterations made during each series of blasts.

The seismographs available were too sensitive to record displacements of damaging levels. Consequently, arrangements were made to obtain the

In order to prevent building damage by fracture of the soil immediately surrounding the charge, precautions were necessary to insure that the blasting charges were located sufficiently far from the buildings. Such precautions were inconvenient to arrange, since achievement of damage to buildings by blasts set off at distances of 100 ft or more would have involved the use of larger quantities of explosive than was practicable. The procedure followed therefore was to set off small calibrating charges at about 150 ft from the buildings and successively larger charges progressively closer, the minimum distance of placement from the buildings in most instances being 50 ft. The depths of the holes for the charges ranged from 15 to 30 ft, and were each dependent on the respective charge placed in the hole and on the collar required to control flying debris and air blast. The larger charges were placed in groups 15 to 25 ft apart and so arranged as to produce a plane wave disturbance approximately representative of a distant blast source. The explosives used were 75 per cent Forcite (Canadian Industries Ltd.) and 60 per cent Special Gel (Dupont), 4 to 5 in. in diameter.

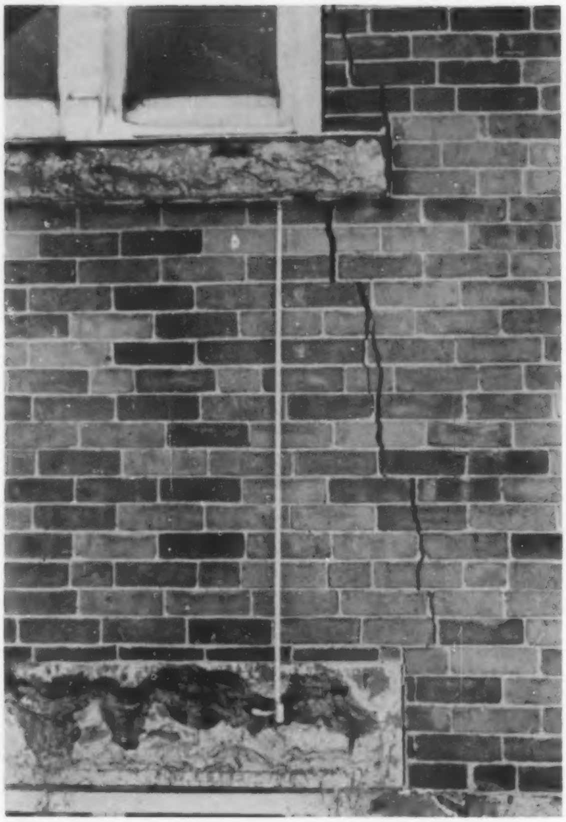


FIGURE 4
A Vertical Crack in a Wall, Indicative of Considerable Differential Settlement

FIGURE 5
A Horizontal Crack in a Basement Wall of a Building Due to Ground Transmitted Vibrations

required values indirectly. A small blast was set off and measurements were made with the seismographs at a number of points each at a different distance from the blast. By using the relation established from a comparison of the values obtained, the displacements caused at the buildings by the test blasts were calculated from results obtained at more distant points.

Arrangements for velocity measurements were similar to those for acceleration measurements, except that, as previously mentioned, only two seismometers were available. Secure mounting and accurate levelling of these instruments were difficult, with the result that the number of reliable velocity records was relatively small. The data recorded therefore consisted mainly of displacement and acceleration measurements. As the analysis proceeded, however, velocity data were found to be significant. Values of velocity therefore were obtained from the other records by calculation.

Building Damage

Definition of Damage

Consideration of the different ways in which various parts of a structure would be stressed as a result of ground-transmitted vibrations, could lead to a number of different explanations of the cause of damage. Such a detailed analysis, though

it might provide a useful understanding in some special instances, would not provide a practical basis for the control of blasting operations.

An alternative approach to the problem is simply to look for an empirical relation between some measure of vibration energy and of building damage. The structures of most buildings are complex, and, as will be shown, so is a typical blasting vibration. Vibration energy in excess of a certain threshold value could stress some portions of a building or of the supporting soil beyond their respective yield points. Whether this damage threshold is sufficiently well defined to serve as a general criterion of safe blasting practice, is questionable. A threshold of damage that is relatively independent of peculiarities of soil or of structure would be the most suitable.

For purposes of relating damage to vibration energy, damage is defined in three categories as follows:

> *Threshold Damage:* widening of old cracks, formation of new plaster cracks, and dislodgment of loose objects such as chimney bricks.
>
> *Minor Damage:* damage that does not affect the strength of the structure, such as broken windows, loosened or fallen plaster, and hairline cracks in masonry.
>
> *Major Damage:* damage that seriously weakens the structure, such as large cracks, shifted foundation and bearing walls, distortion and weakening of the superstructure caused by settlement, and walls out of plumb.

DISCUSSION OF DAMAGE

In general the type of blasting damage was found to be related to the soil on which the buildings stood. In those buildings on sand clay the vertical cracks indicated settlement of a considerable extent. An example of damage of this type is shown in Figure 4. Damage to houses on the glacial till consisted mainly of horizontal cracks and shattered basement walls, indicating damage by wave energy as shown in Figure 5. An interesting feature of the tests was that chimneys were generally the first to show signs of weakness.

Vibration Records

INTERPRETATION OF RECORDS

The blasting vibration quantity usually measured is either displacement or acceleration. Some authorities, for instance Crandell, suggest that the quantity measured is unimportant since the amplitude and frequency of the disturbance (assumed to be sinusoidal) can be used to calculate the corresponding value of the quantity (displacement, velocity, acceleration) needed.

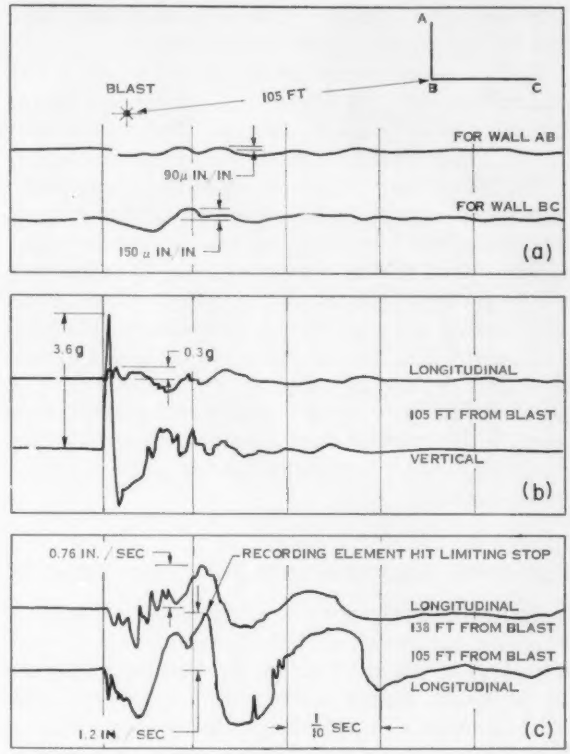


FIGURE 6

Typical Records of
(a) Strain, (b) Acceleration, and (c) Velocity
Measured In and Near Buildings
Erected on Sand Clay

Actual records, however, indicate that Crandell's suggestion is over simplified. Figure 6 shows typical records of acceleration and velocity measurements made at the same observation point for the same blast. The records being quite different in character, any attempted choice of the most characteristic frequency would be arbitrary. Hence it is not possible to use the frequency value with confidence as a means for calculating, for example, velocity from acceleration. Results from the numerical differentiation of the velocity records correlate reasonably well with the corresponding acceleration records. The numerical integration and differentiation of such records is a tedious process. It is obviously better to measure directly the quantity which correlates best with

damage. The precise waveform need therefore not be known, nor even be recorded.

In the present study the maximum velocity was estimated from the steepest slope on the corresponding displacement record. The values initially determined in this manner were systematically lower than observed velocities, but vibration table experiments indicated that the magnification of the Leet seismographs at the frequencies involved varied between 20 and 40 depending on frequency, instead of the rated value of 50. The results were corrected accordingly. No procedure simpler than a complete integration was found for estimating velocity amplitudes from the acceleration records—an unfortunate fact since acceleration records were almost always available for points only a few feet from the point of maximum damage.

Amplitude Variations with Charge and Distance

As noted previously, the seismographs were too sensitive to permit direct measurements of the vibration of the portions of the buildings nearest to the blasts. Hence preliminary steps were taken to determine a satisfactory relation for application to actual measurements made at distant points, to find the displacement values at the most stressed portions of the buildings. With this aim the results were examined to find the relations of displacement amplitude with charge (weight of explosive), and with distance from the blast. This procedure was carried out both with the acceleration and with the displacement records.

The problem of establishing these relations was very complicated, since the observed amplitude at any point depended on several variables besides charge and distance of charge. These other variables include the explosive used and its state of coupling with the surrounding soil; structural peculiarities of the medium; and the state of coupling of the measuring instruments both to the buildings and to the medium. By the choice of records that indicated little or no effect of extraneous variables, however, a relation between displacement amplitude and charge and another between displacement amplitude and distance were obtained. These relations give average values from which individual results may depart considerably.

The variation of amplitude with charge was investigated by comparing amplitude readings for different charges, taken with the same instrument at the same observation point. Each comparison made was between individual readings of a pair chosen such that the difference between the distances of the blasts from the observation point was small. Correction for the difference in distances was made on the assumption that an inverse distance law applied. With the additional

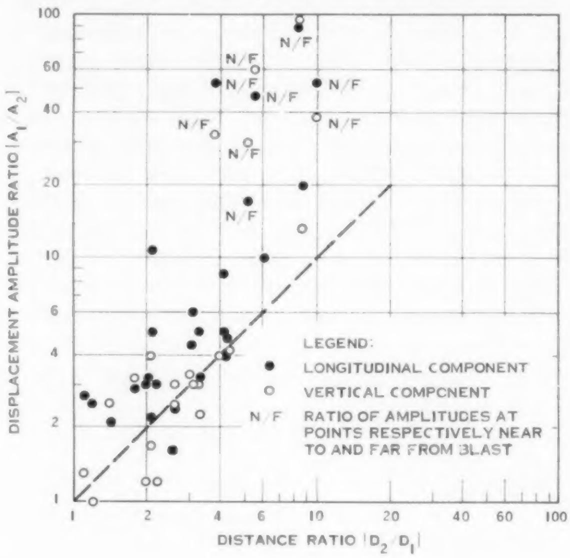


Figure 7

Scatter Diagram of Points Indicating the Relation of Displacement Amplitudes to Corresponding Blast Distances

assumption that the amplitude is proportional to some power of the charge, each pair of readings was used to calculate a value of n in the relation $A_1/A_2 = (E_1/E_2)^n$, where A_1 and A_2 are the amplitudes, and E_1 and E_2 are the weights of the corresponding charges. By this procedure all extraneous variables except the source factor and possibly some local peculiarities of the medium were eliminated. The use of 52 such pairs of observations gave an average value of $n = 0.70$ with a probable error of 0.04. This value is in good agreement with the value $n = 2/3$ given by Thoenen and Windes, rather than with the values given by Morris ($n = 1/2$) and Crandell ($n = 1$).

The results obtained with longitudinal component amplitudes were not significantly different from those obtained with vertical components, nor did the results of the tests on sand clay differ from those of tests on till. Also, no variation in n occurred with change of charge over the range 15 to 750 lb. The average value of 0.75 for n from

the acceleration results was slightly higher than that (0.62) from the displacement results, but this difference is considered to be insignificant.

The variation of n with distance was determined from the means of observations made at pairs of points, each pair being at different distances from the same charge. This procedure eliminated source variations but not the variations associated with the medium and with the observation points. The results were used to obtain values of m in the expression $A_1/A_2 = (d_2/d_1)^m$, where A_1 and A_2 are the amplitudes at distances d_1 and d_2 respectively. An average value obtained for m was 1.8, with a probable error of 0.2, but the distribution of the individual values was unsymmetrical, with by far the larger number very close to 1.0. Variations in the instrument coupling to the medium from observation to observation would be expected to produce a symmetrical distribution, with low as common as high values. Hence the principal cause of variation in the value of m appears to be imperfections in the medium, on the assumption that the inverse distance law is valid for a perfect medium.

The greatest deviations from the inverse distance law were always associated with a marked change either in the terrain or in the method of comparing the vibration records. In the sand clay area a large amplitude low-frequency (2.5 cycles per second) vibration that occurred within a few hundred feet of a blasting source did not occur at all at 1,500 ft and beyond. Ratios of amplitudes from measurements made at points less than 1,500 ft from the blasting source were in fair accord with the inverse distance law, as also were the ratios from measurements taken beyond 1,500 ft. But the ratios of amplitudes from "near" measurements to corresponding amplitudes from "far" measurements, deviated greatly. These ratio values were used to obtain the points labelled N/F in Figure 7, which is a scatter diagram of the distance ratio/amplitude ratio results. In general these studies indicated that a prediction for a distant point based on observations at a near point would be quite conservative, whereas it would be unwise to attempt prediction for a near point from measurements at a distant point.

Incidentally, no evidence was found of the occurrence of a Rayleigh wave or of a surface wave of any other type, for which m would be about 0.7. Only four observations gave values of m less than 0.9.

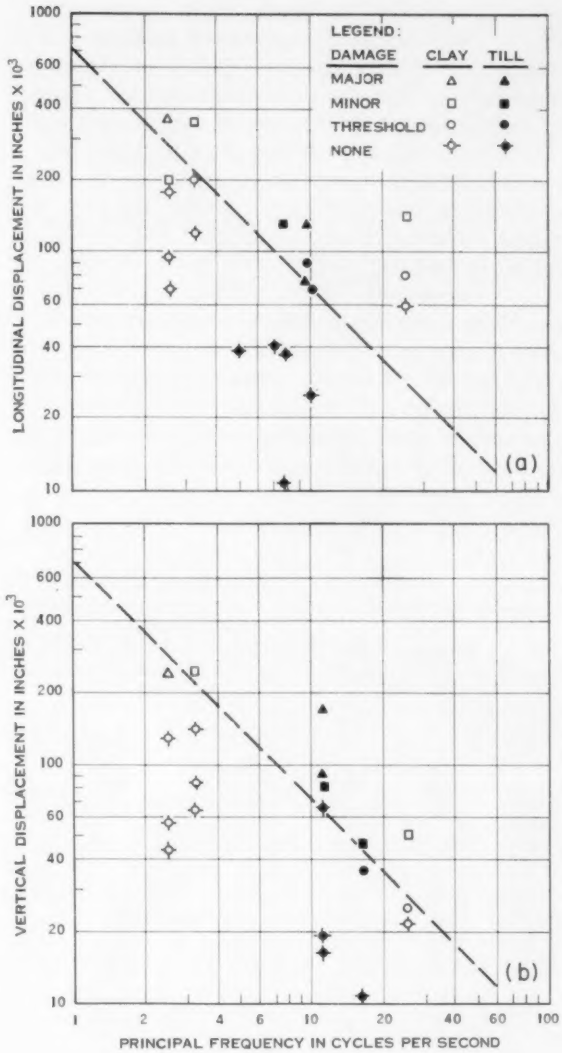


FIGURE 8

Scatter Diagram of Points Indicating the Relations of Damage to Frequency for (a) Longitudinal Displacement and (b) Vertical Displacement

Relations of Damage to Vibration Amplitudes

DISCUSSION RELEVANT TO ST. LAWRENCE TESTS

Significant data obtained in the tests are given in Tables IIA and IIB. The acceleration results were almost all directly obtained for the foundation walls nearest the blast. Nearly all the displacement records were calculated as described previously. The limited velocity observations

usually required a small distance correction. Furthermore, observations were augmented by calculations based on the maximum slopes of displacement records, a procedure which was not entirely satisfactory since no records were obtainable for displacement within the buildings. Hence the calculations necessitated a process of extrapolation, as was used for obtaining displacement values. Nevertheless calculated and observed values of velocity, when both are available, are in fair agreement. Better agreement was found for a few instances in which acceleration records were integrated to obtain maximum velocity.

Figures 8a and 8b are scatter diagrams showing the correlations of longitudinal and vertical displacements and frequency with damage. The results indicate that considerable variation in displacement damage threshold values occur and that these values depend on the principal frequency. In fact the Figures suggest that the thresholds occur at a velocity which is the same in all instances. (The broken lines in the Figures represent in each instance a velocity of 4.5 in. per second, a criterion that will be discussed later). A detailed examination of the Figures shows that, for the sand clay soils, the damage thresholds are grouped in the low frequencies, whereas for the till soils the threshold group is in the high frequencies. These observations seem to indicate some correlation between the soil type and the frequencies at which damage occurs. Apparently the assignment of a damage threshold value in terms of displacement is therefore not possible without some qualification involving frequency.

TABLE IIA

SUMMARY OF BLASTING DATA FOR VERTICAL COMPONENTS

Bldg.*	Charge (lb)	Dist. (ft)	Acceleration Ampl. (g)	Acceleration Freq. (cps)	Displacement Ampl. (in.x10^3)	Displacement Freq. (cps)	Velocity Ampl. (in./sec)	Velocity Freq. (cps)	Settlement (in.)	Horiz. Deform. (in.)	Damage
Sand clay											
C	120	100	3.6	50	(22)	25	(3.0)		0.06	0.1	None
	120	145	2.5	50							None
	142	50	6.1	40	(50)	25	(6.4)		0.95	0.35	Minor
	142	95	5.6	40	(25)	25	(3.1)				Thres.
E	92	120	2	85, 150	(57)	2.5	(2.9)		0.02		None
	92	155	1.6	85, 150	(43)	2.5	(2.1)				None
	280	88	4	130, 70	(130)	2.5	(5.7)		0.11	0.1	None
	280	125	(2.8)	130, 70							None
	140	50	(4.3)	70	(140)	2.5	(6.4)		1.2	0.55	Minor
	140	25	(7)	40	(240)	2.5	(10.7)		5.1	3	Major
S	260	160	1.6	130, 70	(64)	4.6					None
	140	80	2.4	70	(85)	3.2	(3.9)				None
	550	75	15.5	250, 85	(240)	3.2	(10.7)		0.79	0.7	Minor
	550	125	(9.2)	250, 85	(140)	3.2	(6.4)				None
Till											
R	47	200	(0.36)	170, 17	6.7	11	(0.63)			0	None
	75	75	(1.3)	170, 17	(19)	11	(2.3)			0	None
	120	29	(47)	170, 17	(84)	11	(8.3)		0.06	0.12	Minor
T	250	120	1.02	57	(10.7)	16	(0.61)		0	0	None
	350	80	3.6	50	(36)	16	(4.6)		0.02	0.07	Thres.
	650	70	5.2	36	(46)	16	(4.3)		0.07	0.15	Thres.
F	50	140	0.65	50	17	11	(2.0)		0	0	None
	400	90	5.7	130	(86)	11	(10.0)		0.1	0.5	Major
	400	95	6.6	130							Major
	400	115	45	130	(67)	11					None
	750	75	10.5	85	(170)	11	(17)		0.27	1.5	Major
	750	70	9.5	64							Major

* See Table I for details on buildings
Values in parentheses were estimated from related data

The velocity results are plotted in Figure 9. Since many of the velocity values were obtained indirectly, the derivation of a correlation of velocity with frequency was not attempted. Also, despite the extra steps necessary in the derivation, the individual velocity damage threshold values for all six buildings show remarkably good agreement. The damage threshold for both longitudinal and vertical velocity is about 4 in. per second.

The acceleration results are shown in Figures 10a and 10b. Although the results are plotted against principal frequency, it should be remembered that a number of frequencies usually are involved, as can be seen from the acceleration records (Figure 6). In some instances two or three widely differing "principal frequencies," all of about the same amplitude, were recorded, which made difficult the decision regarding the proper frequency to consider. The vertical component of acceleration shows a well defined damage threshold of about 4 *g*. The longitudinal results included one exceptionally low value, but otherwise suggest a damage threshold of between 2 *g* and 3 *g*.

Damage Criteria Based on St. Lawrence Tests Compared with Published Recommended Values

Various criteria of damage and recommended safe limits to prevent blasting damage, based on values of displacement, velocity, and acceleration, have been proposed. A comparison of the St. Lawrence results with these criteria follows.

Thoenen and Windes[1] made exhaustive studies of blasting vibrations and of building damage, but unfortunately these two phases of their work were

TABLE IIB

Summary of Blasting Data for Longitudinal Components

Bldg.*	Charge (lb)	Dist. (ft)	Acceleration Ampl. (g)	Acceleration Freq. (cps)	Displacement Ampl. (in.x10³)	Displacement Freq. (cps)	Velocity Ampl. (in./sec)	Velocity Freq. (cps)	Settlement (in.)	Hor. Def. (in.)	Damage
Sand clay											
C	120	100	0.36	43	(60)	25	1.2+, (4.8)	8	0.06	0.1	None
	120	145	0.3	43			0.76				None
	142	50	0.7	64	(140)	25	4.8+, (10.6)	8	0.95	0.35	Minor
	142	95	0.5	64	(80)	25	34				Thres.
E	92	120	0.55	250	(94)	2.5	2.2, (1.5)	8	0.02		None
	92	155	0.66		(72)	2.5	1.7, (1.1)				None
	280	88	2.7	125	(180)	2.5	(3.3)		0.11	0.1	None
	140	50	2.6+	70	(200)	2.5	(7.7)		1.2	0.55	Minor
	140	25	(8.5)	50	360	2.5	(16)		5.1	3	Major
S	260	160	0.8	250			1.3	50			None
	140	80	0.8	250	(120)	3.2	2	150			None
	550	75	2.8	250	(350)	3.2	(10)		0.79	0.7	Minor
	550	125	1.7	250	(200)	3.2	(6.0)				None
Till											
R	47	200	(0.26)	460, 13	10.4	7.7	0.46, (0.55)			0	None
	75	75	(1.0)	460, 13	(38)	7.7	(1.9)			0	None
	120	29	(3.5)	460, 13	(130)	7.7	6.8	10	0.06	0.12	Minor
T	250	120	1.05	15, 43	(40)	7	(2.9)		0	0	None
	250	145	0.7	15, 43			2.4	13			None
	350	80	2.5	50	(72)	10	10, (7.0)	10, 7.3	0.02	0.07	Thres.
	650	70	4.8	50	(90)	9.5	(10+), (4.3)**	6.5	0.07	0.15	Thres.
	650	100	(3.4)	50	(63)	9.5	7+				None
F	50	140	0.75	42	25	10	1.4, (1.7)	100, 8.5	0	0	None
	400	90	5.3+	170	(75)	9.5	8+, (6.7)		0.1	0.5	Major
	400	95	4.0	170			8+				Major
	400	115	4.1		(39)	5					None
	750	75	6.0	85	(128)	9.5	(12)				Major
		70	8.0	85							Major

* See Table I for details on buildings
** Calculated by different method
Values in parentheses were estimated from related data

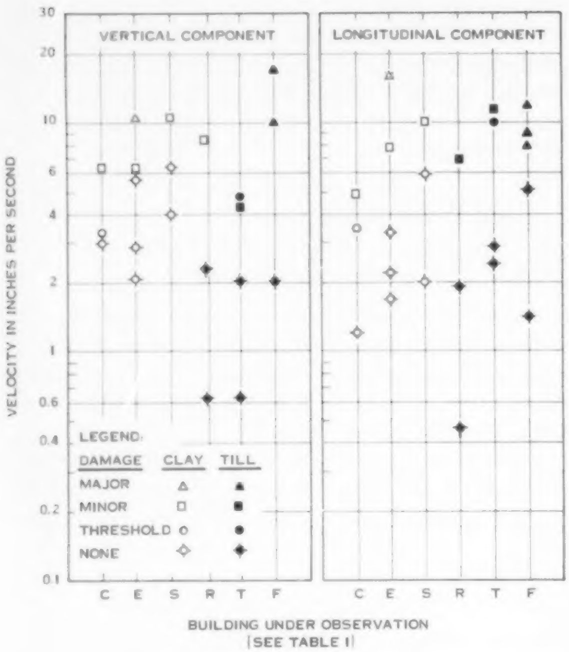


FIGURE 9

Scatter Diagrams of Points Indicating the Relations of Damage to Respectively the Vertical and Longitudinal Components of Velocity

not entirely related. Measurements made of the damage done to ceiling panels in buildings by mechanical vibration, indicated an acceleration damage threshold (in terms of the present definition) of about 0.7 *g*. Only one instance of damage due to a blasting operation was discussed, a displacement amplitude threshold of about 0.1 in. being reported. This value corresponds to those that occur about the middle of the frequency curves obtained from the St. Lawrence study.

The threshold acceleration values obtained in the St. Lawrence study were substantially higher than the corresponding result obtained by Thoenen and Windes by the mechanical vibration method (2 to 4 *g* in contrast to 0.7 *g*).

The difference between these values occurred not only for accelerations at ground level, but also for measurements made in the upper parts of the buildings. Apparently therefore, the level of steady-state mechanically induced vibration at which damage or failure is produced is lower than that of the transient vibration due to blasting. At this point the fact may be noted that the primary damage-causing vibration observed in the St. Lawrence work was never similar to the simple transverse motion in a free panel, studied by Thoenen and Windes.

Morris,[3] on the basis of strength calculations for brick piers, recommended as a safe limit a displacement of 8×10^{-3} in. More recently Morris and Westwater,[6] on the basis of a few observations of damage to buildings, estimated that the actual damage threshold is about 40×10^{-3} in. This value is in agreement with those in the high frequency end of the spectrum of Figure 8b (for buildings on till), but is much lower than those in the low-frequency spectrum (for buildings on sand clay). To complete the picture, Langefors et al recommended a much lower displacement threshold for buildings founded on rock (about 1.6×10^{-3} in.). Hence Morris' originally recommended limit is conservative except for buildings on rock.

Crandell[2] recommends a velocity criterion based on peak energy in the disturbance. He specified a value of 3.2 in. per second as the beginning of a "caution zone" and of 4.5 in. per second as the beginning of the "danger zone." Although the value of 4.5 in. per second is assumed to correspond to the damage threshold, he gives no substantiating evidence. The more recent papers by Langefors, Westerberg and Kihlstrom[4] include records of a large number of experimental observations of damage by blasting to houses built on rock, which indicate that the damage threshold is about 4.5 in. per second. The thresholds indicated by the St. Lawrence tests, for both longitudinal and vertical components of velocity, agree very well with this value. As will be recalled, the St. Lawrence tests were carried out on sand clay and on till. The net result of these comparisons appears to be that, for a variety of foundation conditions, and a corresponding variety of damage-causing vibration components involving principal frequencies ranging from 2.5 to 400 cycles per second, the velocity threshold of damage value appears to be 4.5 in. per second.

Observations with Falling Pin Gauge

The pin gauges were installed in a building on sand clay and in others on till. For all the buildings the level of the vibration that caused the pins to fall over was less than damage levels. The relevant data are given in Table III. From these rather limited data, establishment is difficult of a precise threshold vibration level based on the falling pin gauge method.

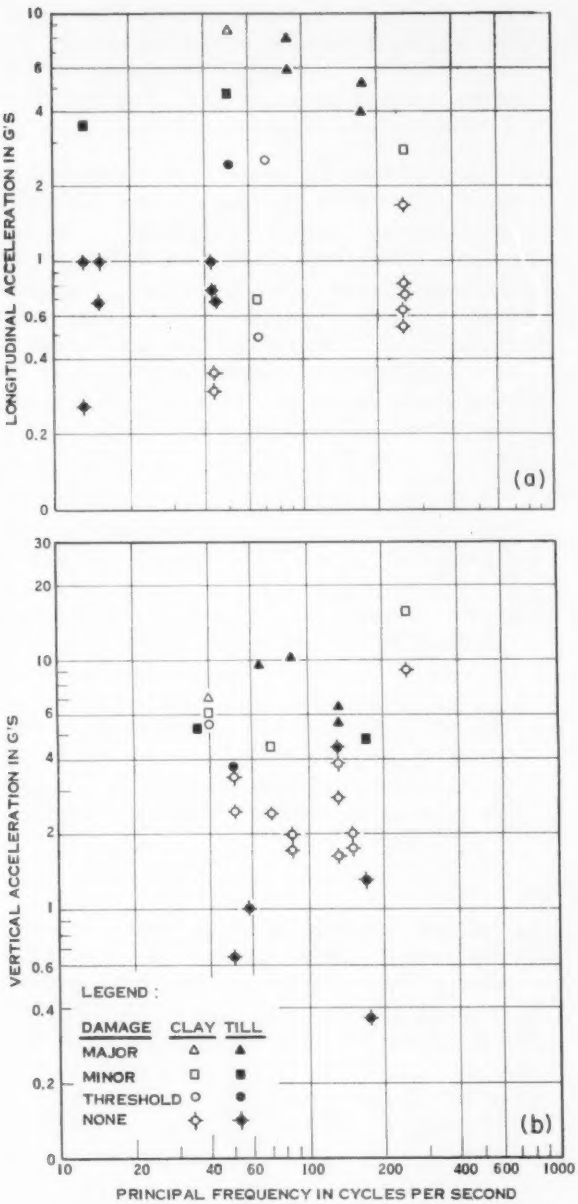


FIGURE 10

Scatter Diagrams of Points Indicating the Relations of Damage to Frequency for (a) Longitudinal Acceleration and (b) Vertical Acceleration

Building Strain

The results of the building strain measurements were reasonably consistent, the strain indicated increasing with charge. Also, a high degree of settlement was associated both with large dynamic strain, and, following the blast, with permanent strain in the walls. Strain records indicated that wherever settlement was small, the wall returned to its original condition. In one house the dynamic strain imposed in the walls was insufficient to cause even minor cracking although shear cracks occurred in the basement walls. As may be recalled, strain gauges were attached to thin steel strapping secured at diagonally opposite corners of the walls. The records showed that the total strain in the strapping was not equal to the total dynamic strain in the wall in all instances. As a result some flattening is evident at the peaks of the strain curves (Figure 6). Also, since the measuring system indicated the average strains over long lengths of wall, maximum local strains were not recorded. Further, since the records showed a very low rate of change of strain, the strapping was insensitive to the sharp peaks in strain. The conclusion reached was that this method of measuring strain was somewhat inadequate.

Air Blast

None of the window breakage that occurred in any of the six structures could be attributed to air blast. The maximum value recorded of air-blast pressure in the tests was 25 lb per sq ft; Windes[7] has found that pressures less than 100 lb per sq ft will not cause window breakage.

In one of the frame houses studied, however, an interesting instance of window breakage occurred in the final blasting operation. Most of the windows in the walls longitudinal to the blast were broken, whereas those in the transverse walls remained intact, even though one of these walls was only 29 ft from the blast. The breakage was attributed to the longitudinal component of the ground vibration which caused a rocking motion of the structure.

Relations of Damage to Charge and Distance

The relation between building damage and ground vibration is of interest since it permits a detailed examination of existing criteria. Control of blasting operations, however, would be simpler if safe limits based directly on explosive charge and distance could be set. The St. Lawrence results have been examined for a correlation between damage and the relation $E^{2/3}/d$, where E is the weight of the charge in pounds and d is its distance in feet from the observation point. As

can be seen in Figure 11, the damage threshold derived on this basis, although reasonably well defined, is not quite as good as that obtained from velocity measurements. Figure 11 also permits a comparison of the results with those recommended by Crandell, Morris, and Langefors et al.

The formula $E^{2/3}/d = 0.1$, which includes a safety factor of 3, might be recommended as the criterion for insuring safety. This formula would possibly need alteration if blasting data for greater ranges of charge and distance were available. For heavy charges and long distances, studies must necessarily await large blasting operations. Studies of blasting with small charges at distances less than say 30 ft, however, can readily be done. Blasting at the shorter ranges has already been considered by Langefors et al, and their recommended safe limit, which is applicable for a distance as small as 3 ft, is shown in Figure 11.

Conclusions

1. The results of the study indicate a well-defined vibration threshold above which building damage may be expected. The St. Lawrence work shows that either acceleration or velocity may be used as an index of damage for the two soil types studied. Since in this work essentially the same velocity criterion was deduced as from the Swedish studies on rock, velocity appears to be largely independent of terrain. The value of velocity at which damage is likely to occur is 4 to 5 in. per second. A safe limit of 2 in. per second is recommended.

2. In general the vibration records are very complex, and there is no simple method by which the maximum velocity amplitude can be calculated either from displacement or from acceleration records. Hence for monitoring purposes a direct measurement of velocity is desired. This monitoring might be done by means of a velocity-sensitive transducer or by an accelerometer combined with a suitable integrating network. The instrumentation problem is now being studied.

3. For single charges the St. Lawrence studies indicate that the damage threshold is given approximately by $E^{2/3}/d = 0.3$. The formula of $E^{2/3}/d = 0.1$, which includes a safety factor of 3, is recommended as a means of calculating a safe limit for normal blasting operations. This formula agrees approximately with the Swedish recommendation which is applicable to very small charges and distances, thus indicating its general applicability for most soils and for wide ranges of charges and distances. No observations were made for multiple

TABLE III

FALLING PIN GAUGE OBSERVATIONS COMPARED WITH CORRESPONDING DATA ON LONGITUDINAL COMPONENTS OF VIBRATION AND WITH BUILDING DAMAGE

Building*	Pin Location	Acceleration (g)	Displacement (in. x 10^3)	Velocity (in./sec)	Damage	No. of Pins Upset
Sand clay						
S	Basement	0.8	120	2.0	None	8
	Basement	0.2	220	1.5	None	8
	Basement	1.7	200	10.0	Minor**	8
Till						
T	Basement	(1.9)	55	7.5	Thres.	3***
	Road	(1.0)	8	2.8		0
	Basement	3.4	(63)	7.0	Minor	8
	Road	(0.8)	(22)	2.5		0
F	Basement	0.6	15	1.4	None	0
	Basement	4.0	75	8.0+	Major	8
	2nd Floor	3.6		8.0+	Major	8

* See Table I for details of buildings
** Charge was detonated at distance of 75 ft
*** The shortest (6 in.) and the two longest (15 in.) pins fell
Values in parentheses were estimated from related data

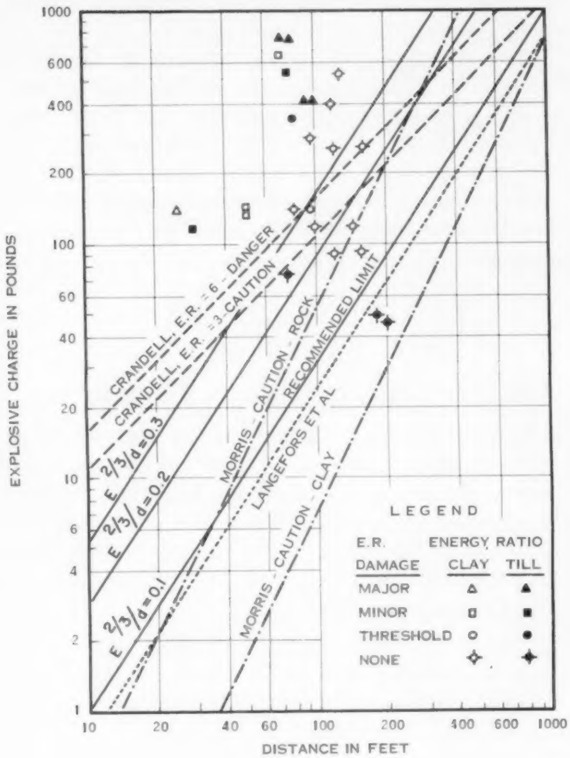


FIGURE 11

Diagram Showing the Relations of Damage to the Various Limits Recommended From the Results of the St. Lawrence Study and of Studies Undertaken by Other Workers

charges involving delay systems. Information obtained from others, however, indicates that delays of the order of a few milliseconds between charges may produce a cumulative effect somewhat greater than the amplitude due to an equivalent individual charge. An additional safety factor of two should therefore be applied to the formula for calculating the maximum charge per delay.

4. Should blasting that would cause vibration approaching the damage threshold be necessary, preliminary instrument monitoring is desirable. The safest procedure is to begin with one or more test blasts with charges less than those expected to be used, to determine the energy propagation from the source to the structures concerned. The test blasts should, however, be placed in the same area as the operating blasts, since the vibration amplitude may vary unpredictably with location.

5. The traditional falling pin gauge was unexpectedly successful as an indicator of the damage threshold. It appears that if an array of 1/4 in. diameter pins varying in length from 6 in. to about 18 in. is used, at least some pins will fall before the damage threshold is reached. A further study of the pin gauge and similar devices is planned.

Acknowledgment

The authors are especially appreciative of the interest and co-operation of Mr. Gordon Mitchell, then Director of the St. Lawrence Power Project, and his staff, in this investigation./NCSA

REFERENCES

1. THOENEN, J. R. and WINDES, S. L., Seismic Effects of Quarry Blasting, *U. S. Bureau of Mines Bulletin 442*
2. CRANDELL, F. J., *Journal, Boston Society Civil Engineers*, April, 1949, pp 222-245
3. MORRIS, G., *The Engineer*, 190, p 394 and p 414 (October 27, November 3, 1950)
4. LANGEFORS, WESTERBERG and KIHLSTROM, *Water Power*, September (p 335), October (p 390), November (p 421), 1958
5. ROCKWELL, E. H., Vibrations Caused by Blasting and Their Effect on Structures, Publication, Hercules Powder Co., Wilmington, Delaware, 1934
6. MORRIS, G. and WESTWATER, R., Damage to Structures by Ground Vibration due to Blasting, *Mine and Quarry Engineering*, April 1953, pp 116-118
7. WINDES, S. L., Damage from Air Blast, *U. S. Bureau of Mines, Report R.I. 3622*, February, 1942

In Memoriam

(Continued from page 8)

of Directors of the Manufacturers Division for 16 years; as Vice Chairman for the period from 1943-1948; and was one of the Manufacturers Division's representatives on the NCSA Board in 1947. It was the sincere desire of his colleagues in the Division that he accept the Chairmanship, the highest honor which they could convey. This he felt he should not do, prompted, we are sure, by his sincere feeling that younger men should move more rapidly into the roles of leadership.

We always will cherish this memory of Mose who, through the sincere warmth of his hand clasp, the spontaneous humor of his stories and anecdotes, and his constant readiness to help out in any emergency, has left upon our memory the indelible imprint of a fine gentleman, a wise counselor, and a true friend.

The National Crushed Stone Association and its Manufacturers Division extend to the family and business associates of L. C. Mosley heartfelt sympathy in their bereavement./NCSA

$3 Billion Federal Aid Highway Funds

(Continued from page 9)

United States has indicated that the apportionments for the fiscal years 1957-61 had not been made in strict accordance with the governing legislation, in that post road mileage data as of June 30 next preceding the date of each apportionment should have been used. Since the apportionments for those years were made during the summer or early fall, at a time when June 30 post road mileages for the same year were not yet available, the Bureau of Public Roads had used the data for the prior June 30 in each case. The ABC apportionments for the fiscal years 1957-61 have now been recalculated, using the appropriate post road mileage data, and the corresponding adjustments have been made in the 1963 apportionment.

The amounts of the ABC apportionments for 1963 for each state were calculated according to the prescribed formulas, the combined amount of the adjustments necessary both because of the revised census data as it affected the 1962 apportionment and the post road mileage data as it affected the 1957-61 apportionments, and finally the actual adjusted apportionments.

Twenty-five states receive somewhat more under the adjusted apportionment than they would have from the apportionment as initially calculated, and 27 states receive less. It is emphasized that these changes are adjustments of prior year apportionments. A state now receiving less than the basic calculated amount has already received that amount of federal aid in previous years, and actually suffers no loss.

Federal-Aid Program Progress

Recent figures show that over one-fourth of the 41,000 mile interstate system is now in actual use. Of the 10,825 miles open to traffic, 5,500 miles are built to standards adequate for 1975 traffic, and 3,005 miles are improved to full capability for handling current traffic but need further improvement to bring them up to the standards for 1975. Toll roads, bridges, and tunnels incorporated into the system, as permitted by law, total 2,270 miles.

In addition, 4,847 miles of the interstate system are under construction and on another 10,052 miles engineering or right-of-way acquisition is in progress. More than $11.2 billion has been put to work on the interstate system since the accelerated program began 5 years ago.

The continuing program of federal assistance for the improvement of the federal aid primary and secondary highway systems and their urban extensions has also made an outstanding record of progress, with $11.4 billion worth of work involving nearly 146,000 miles of construction contracts completed or put under way since 1956. /NCSA

Road Evaluation Officers Named

Federal Highway Administrator Rex M. Whitton recently assigned five men with long investigative experience to serve as Regional Program Evaluation Officers for the federal-state highway program in ten regions comprising the 50 states and the District of Columbia. The appointees and their assignments are:

Joseph M. O'Connor, Kensington, Md., to the area comprising New York, New Jersey, Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, and Connecticut.

George F. McInturff, Chevy Chase, Md., to the States of Minnesota, Iowa, Missouri, North and South Dakota, Nebraska, Kansas, Wyoming, Utah, Colorado, and New Mexico.

William C. Thornton, Bethesda, Md., to the States of Washington, Oregon, Montana, Idaho, California, Nevada, Arizona, Alaska, and Hawaii.

Frank A. Stanton, Annandale, Va., to the States of Wisconsin, Michigan, Illinois, Indiana, Kentucky, Ohio, Pennsylvania, Virginia, West Virginia, Maryland, Delaware, and the District of Columbia.

Virgil M. Redwine, Bethesda, Md., to the States of Oklahoma, Texas, Arkansas, Louisiana, Tennessee, North and South Carolina, Mississippi, Alabama, Georgia, and Florida.

Whitton said that the primary responsibility of the five Regional Program Evaluation Officers will be the investigation of any known or possible irregularities that may appear in the nationwide federal-aid highway program. Program Evaluation Officers, Whitton pointed out, work closely with federal and state highway officials in maintaining the high standards prescribed for federal highway work./NCSA

Manufacturers Division
National Crushed Stone Association

•

These associate members are morally and financially aiding the Association in its efforts to protect and advance the interests of the crushed stone industry. Please give them favorable consideration whenever possible.

•

Acme-Hamilton Manufacturing Corp.
Meade St., Trenton 3, N. J.
Belts; Hose

Allis-Chalmers Manufacturing Co.
P. O. Box 512, Milwaukee 1, Wis.
Air Compressors; Bulldozers, Scrapers, Elevating Graders; Car Shakeouts; Castings — Iron, Alloy Iron; **Crushers, Pulverizers; Dryers** — Aggregate; **Electrical Apparatus; Engines** — Diesel, Gasoline; **Loaders** — Tractor; **Motors** — Electric; **Power Generating and Distributing Systems; Pumps; Screens** — Vibrating, Shaking, Revolving; **Speed Reducers; Tractors** — Crawler; **Washing Equipment**

American Cyanamid Co.
Explosives and Mining Chemicals Dept.
30 Rockefeller Plaza, New York 20, N. Y.
Explosives, Blasting Supplies

American Manganese Steel Division
American Brake Shoe Co.
155 North Wacker Drive, Chicago 6, Ill.
Castings; Chains; Conveyors — Apron Feeder; **Crushers, Pulverizers** — Parts; **Dippers** — Shovel; **Grizzlies; Pumps; Steel** — Alloy, Carbon; **Welding Equipment and Supplies**

American Pulverizer Co.
1249 Macklind Ave., St. Louis 10, Mo.
Crushers — Ring, Hammermills, Impactors, Reversible, Laboratory

Atlas Chemical Industries Inc.
Wilmington 99, Del.
Explosives, Blasting Supplies

Austin Powder Co.
55 Public Square, Cleveland 13, Ohio
Explosives, Blasting Supplies

Bacon-Greene & Milroy
Division W. H. Milroy & Co., Inc.
P. O. Box 5097, Hamden 18, Conn.
Bins; Conveyors — Belt; **Crushers, Pulverizers** — Jaw; **Elevators** — Bucket; **Feeders; Plant Design and Layout; Plants; Screens** — Vibrating

Baldwin-Lima-Hamilton Corp.
Construction Equipment Division
South Main St., Lima, Ohio
Asphalt Plants; Bins; Conveyors — Belt; **Crushers, Pulverizers; Dryers** — Aggregate; **Dust Control Equipment; Feeders; Loaders** — Tractor; **Plant Design and Layout; Plants; Shovels, Draglines, Cranes, Clamshells; Washing Equipment**

Barber-Greene Co.
400 North Highland Ave., Aurora, Ill.
Asphalt Plants; Belts — Conveyor, Elevator; **Bin Gates; Bins; Buckets** — Elevator; **Conveyors** — Belt; **Dryers** — Aggregate; **Dust Control Equipment; Elevators; Feeders; Loaders** — Bucket; **Plant Design and Layout; Plants; Screens** — Vibrating, Shaking, Revolving

Berlin Construction Co., Inc.
Depot Road, Berlin, Conn.
Bins; Conveyors — Belt; **Plant Design and Layout; Plants**

Birdsboro-Buchanan Crusher Dept.
Birdsboro Corp.
1941 Furnace St., Birdsboro, Pa.
Crushers, Pulverizers — Jaw, Roll

Manufacturers Division – National Crushed Stone Association
(continued)

Brunner & Lay-Southern, Inc.
P. O. Box 5235, Asheville, N. C.
Bits — Rock; **Steel** — Alloy, Carborized

Bucyrus-Erie Co.
South Milwaukee, Wis.
Bits — Rock; **Buckets** — Dragline; **Dippers** — Shovel; **Drills, Drilling Equipment, Supplies; Shovels, Draglines, Cranes, Clamshells**

Buffalo Springfield Co.
Division of Koehring Co.
1210 Kenton St., Springfield, Ohio
Drills, Drilling Equipment — Rotary, Churn

Buffalo Wire Works Co., Inc.
320 Terrace, Buffalo 2, N. Y.
Screen Sections — Wire Cloth

Canadian Industries Ltd.
P. O. Box 10, Montreal, Quebec, Canada
Explosives, Blasting Supplies

Cape Ann Anchor & Forge Co.
P. O. Box 360, Gloucester, Mass.
Drop Balls

Chain Belt Co.
P. O. Box 2022, Milwaukee 1, Wis.
Bearings; Bin Gates; Bins; Buckets — Elevator; **Castings** — Iron, Alloy Iron; **Chains; Conveyors** — Belt, Apron, Chain, Drag, Flight, Vibrating; **Elevators; Feeders; Grizzlies; Pillow Blocks; Plant Design and Layout; Plants; Pumps; Screens** — Vibrating, Shaking, Revolving

Church, H. F., Inc.
P. O. Box 72, Farmington, Conn.
Drilling — Contract

Clark Equipment Co.
Construction Machinery Division
P. O. Box 599, Benton Harbor, Mich.
Bulldozers, Scrapers, Elevating Graders; Loaders — Tractor; **Shovels, Draglines, Cranes, Clamshells; Tractors** — Truck

Continental Conveyor & Equipment Co.
P. O. Box 398, Winfield, Ala.
Conveyors — Belt, Flight, Screw; **Elevators** — Bucket; **Feeders; Pillow Blocks**

Contractors and Engineers Magazine
470 Park Ave., South, New York 16, N. Y.
Publications — Trade

Cross Perforated Metals Plant
National-Standard Co.
P. O. Box 507, Carbondale, Pa.
Screen Sections — Plate; **Screens** — Vibrating, Shaking, Revolving

Cummins Engine Co., Inc.
1000 Fifth St., Columbus, Ind.
Engines — Diesel

Deister Machine Co.
1933 East Wayne St., Fort Wayne 4, Ind.
Classifiers; Screens — Vibrating, Shaking; **Washing Equipment**

Derrick Manufacturing Corp.
590 Duke Road, Buffalo 25, N. Y.
Screens — Vibrating, Shaking, Revolving; **Testing Sieves and Sieve Shakers**

Diamond Iron Works
Division Goodman Manufacturing Co.
Halsted St. and 48th Place, Chicago 9, Ill.
Belts — Conveyor, Elevator; **Bins; Buckets** — Elevator; **Conveyors** — Belt; **Crushers** — Jaw, Roll, Hammermills; **Feeders** — Apron, Plate; **Plant Design and Layout; Plants; Screens** — Vibrating, Shaking, Revolving; **Washing Equipment**

Differential Co.
P. O. Box 238, Findlay, Ohio
Cars — Mine, Quarry; **Locomotives; Trucks, Trailers, Truck Bodies**

Dixon Supply Co.
3104 Fourth Ave., South, Birmingham 5, Ala.
Conveyors — Belt

Drill Carrier Corp.
P. O. Box 628, Salem, Va.
Drills, Drilling Equipment, Supplies

Manufacturers Division – National Crushed Stone Association
(continued)

Du Pont of Canada Ltd.
85 Eglinton Ave., East, Toronto 12, Ontario, Canada
Explosives, Blasting Supplies

Du Pont, E. I., de Nemours & Co.
Wilmington 98, Del.
Explosives, Blasting Supplies

Dustex Corp.
25 Anderson Road, Buffalo 25, N. Y.
Dust Control Equipment; Feeders

Eagle Crusher Co., Inc.
900 Harding Way East, Galion, Ohio
Bins; Buckets — Elevator; **Conveyors** — Belt; **Crushers, Pulverizers; Feeders; Loaders** — Bucket; **Plant Design and Layout; Plants; Screens** — Revolving

Eagle Iron Works
P. O. Box 934, Des Moines 4, Iowa
Castings — Iron, Alloy Iron; **Classifiers; Drop Balls; Washing Equipment**

Easton Car & Construction Co.
Easton, Pa.
Cars — Mine, Quarry; **Trailers, Truck Bodies** — Off Highway

Ensign-Bickford Co.
660 Hopmeadow St., P. O. Box 308, Simsbury, Conn.
Blasting Supplies

Eriez Manufacturing Co.
1945 Grove Drive, Erie, Pa.
Feeders; Separators — Magnetic; **Vibrators** — Bins and Chutes

ESCO Corp.
1017 Griggs St., Danville, Ill.
Buckets — Clamshell, Dragline; **Castings** — Manganese, Alloy Steel; **Chains; Dippers** — Shovel; **Steel** — Alloy, Carbon

Euclid Division
General Motors Corp.
Hudson, Ohio
Bulldozers, Scrapers, Elevating Graders; Loaders — Tractor; **Tractors; Trucks, Trailers, Truck Bodies** — Off Highway

Flexible Steel Lacing Co.
4607 Lexington St., Chicago 44, Ill.
Fasteners

Frog, Switch & Mfg. Co.
Manganese Steel Dept.
Carlisle, Pa.
Castings — Manganese; **Dippers** — Shovel; **Screen Sections** — Plate

Gardner-Denver Co.
South Front St., Quincy, Ill.
Air Compressors; Bits — Rock; **Drills, Drilling Equipment, Supplies; Pumps**

General Electric Co.
Locomotive & Car Equipment Dept.
2901 East Lake Road, Erie 1, Pa.
Electrical Apparatus — Motors, Generators, Control Rectifiers; **Locomotives** — Diesel Electric, Electric, Battery; **Trucks** — Off Highway

Gill Rock Drill Co., Inc.
P. O. Box 251, Lebanon, Pa.
Bits — Rock; **Drills, Drilling Equipment, Supplies**

Gilson Screen Co.
110 Center St., Malinta, Ohio
Testing Sieves and Sieve Shakers

Goodrich, B. F., Industrial Products Co.
500 South Main St., Akron 18, Ohio
Belts; Hose; Tires, Tubes

Goodyear Tire & Rubber Co.
Akron 16, Ohio
Batteries; Belts; Hose; Tires, Tubes

Manufacturers Division — National Crushed Stone Association
(continued)

Gulf Oil Corp.
Gulf Bldg., 710 Main Street, Houston 2, Texas
Batteries; Lubricating Oils, Greases, Gasoline, Diesel Fuels; Tires, Tubes

Harnischfeger Corp.
4400 West National Ave., Milwaukee 46, Wis.
Engines — Diesel; **Hoists** — Drum; **Power Generating and Distributing Systems; Shovels, Draglines, Cranes, Clamshells; Welding Equipment and Supplies**

HarriSteel Products Co.
420 Lexington Ave., New York 17, N. Y.
Screen Sections — Wire Cloth

Heidenreich, E. Lee, Jr.
Consulting Engineers
75 Second St., Newburgh, N. Y.
Consulting Engineers; Plant Design and Layout

Hendrick Manufacturing Co.
Carbondale, Pa.
Buckets — Elevator; **Grating; Screen Sections** — Plate; **Screens** — Vibrating, Shaking, Revolving

Hercules Powder Co.
Wilmington 99, Del.
Explosives, Blasting Supplies

Hetherington & Berner, Inc.
701-745 Kentucky Ave., Indianapolis 7, Ind.
Asphalt Plants; Dryers — Aggregate; **Feeders**

Hewitt-Robins Incorporated
666 Glenbrook Road, Stamford, Conn.
Bearings; Belts; Bin Gates; Bins; Buckets — Elevator; **Car Pullers; Car Shakeouts; Classifiers; Conveyors** — Belt, Wire; **Crushers, Pulverizers; Elevators; Feeders; Hoists** — Drum; **Hose; Indicators** — Bin Level; **Pillow Blocks; Plant Design and Layout; Plants; Screen Sections; Screens** — Vibrating, Shaking, Revolving; **Speed Reducers; Vibrators** — Bins and Chutes; **Washing Equipment**

Hoyt Wire Cloth Co.
P. O. Box 1577, Lancaster, Pa.
Bucker-Up Strips — Rubber; **Screen Sections** — Wire Cloth

Hughes Tool Co.
P. O. Box 2539, Houston 1, Texas
Bits — Rock; **Drills, Drilling Supplies**

Ingersoll-Rand Co.
11 Broadway, New York 4, N. Y.
Air Compressors; Bits — Rock; **Blowers and Fans; Drills, Drilling Equipment, Supplies; Engines** — Diesel, Gasoline; **Hoists** — Drum; **Hose; Pumps**

International Harvester Co.
Construction Equipment Division
P. O. Box 270, Melrose Park, Ill.
Bulldozers, Scrapers, Elevating Graders; Engines — Diesel, Gasoline; **Loaders** — Tractor; **Tractors** — Crawler, Truck; **Trucks, Trailers, Truck Bodies**

Iowa Manufacturing Co.
916 16th St., N. E., Cedar Rapids, Iowa
Asphalt Plants; Belts — Conveyor, Elevator; **Bins; Classifiers; Conveyors** — Belt; **Crushers, Pulverizers; Dryers** — Aggregate; **Dust Control Equipment; Feeders; Grizzlies; Plant Design and Layout; Plants; Screen Sections; Screens** — Vibrating, Shaking, Revolving; **Washing Equipment**

Jaeger Machine Co.
550 West Spring St., Columbus 16, Ohio
Air Compressors; Hoists — Drum; **Pumps**

Jaques Bros. Ltd.
Griffiths and Palmer Sts., Richmond, Victoria, Australia
Crushers, Pulverizers; Elevators; Feeders; Plants; Screens — Vibrating, Shaking, Revolving; **Shovels, Draglines, Cranes, Clamshells**

Manufacturers Division – National Crushed Stone Association
(continued)

Jeffrey Manufacturing Co.
815 North Fourth St., Columbus 16, Ohio

Bin Gates; Blowers and Fans; Buckets — Elevator; **Car Pullers; Chains; Clutches; Conveyors** — Belt, Apron, Vibrating, Screw, Bucket, Slat; **Crushers, Pulverizers; Dryers** — Aggregate; **Elevators** — Bucket; **Feeders; Grizzlies; Indicators** — Bin Level; **Locomotives; Pillow Blocks; Screens** — Vibrating, Shaking, Revolving; **Vibrators** — Bins and Chutes; **Washing Equipment**

Joy Manufacturing Co.
333 Henry W. Oliver Bldg., Pittsburgh 22, Pa.

Air Compressors; Bits — Rock; **Blowers and Fans; Car Pullers; Conveyors** — Belt, Idlers; **Drilling** — Contract; **Drills, Drilling Equipment, Supplies; Dust Control Equipment; Hoists** — Drum

Kennedy Van Saun Mfg. & Eng. Corp.
405 Park Ave., New York 22, N. Y.

Bins; Blowers and Fans; Buckets — Elevator; **Castings** — Iron, Alloy Iron; **Classifiers; Conveyors** — Belt, Apron, Pneumatic; **Crushers, Pulverizers; Dryers** — Aggregate; **Elevators; Feeders; Pillow Blocks; Plant Design and Layout; Plants; Screens** — Vibrating, Shaking, Revolving; **Washing Equipment**

Kensington Steel Division
Poor & Co., Inc.
505 East Kensington Ave., Chicago 28, Ill.

Buckets — Elevator; **Castings** — Manganese, Alloy Steel; **Chains; Conveyors** — Drag; **Crushers, Pulverizers** (Parts); **Elevators; Feeders** (Parts); **Screen Sections** — Plate; **Shovels, Draglines, Cranes, Clamshells** (Parts); **Tractors** — Crawler (Parts)

Koehring Division
Koehring Co.
3026 West Concordia Ave., Milwaukee 16, Wis.

Buckets — Clamshell, Dragline; **Dippers** — Shovel; **Loaders** — Bucket; **Shovels, Draglines, Cranes, Clamshells; Trucks, Trailers, Truck Bodies** — Off Highway

Lecco Machinery & Engineering Co.
New Airport Road, Bluefield, W. Va.

Conveyors — Vibrating; **Feeders; Screens** — Vibrating, Shaking; **Vibrators** — Bins and Chutes

Le Roi Division
Westinghouse Air Brake Co.
North Main Ave. and Russell Road, Sidney, Ohio

Air Compressors; Bits — Rock; **Drills, Drilling Equipment**

LeTourneau-Westinghouse Co.
2301 North Adams St., Peoria, Ill.

Bulldozers, Scrapers, Elevating Graders; Tractors — Rubber Tired; **Trucks, Trailers, Truck Bodies** — Off Highway; **Wire Rope and Related Products**

Link-Belt Co.
300 West Pershing Road, Chicago 9, Ill.

Bearings; Belts; Bin Gates; Bins; Buckets — Clamshell, Dragline; **Buckets** — Elevator; **Car Pullers; Car Shakeouts; Castings** — Iron, Alloy Iron; **Chains; Classifiers; Clutches; Conveyors** — Belt; **Dippers** — Shovel; **Dryers** — Aggregate; **Elevators; Feeders; Grizzlies; Pillow Blocks; Plant Design and Layout; Plants; Screen Sections** — Plate; **Screens** — Vibrating, Shaking, Revolving; **Shovels, Draglines, Cranes, Clamshells; Speed Reducers; Vibrators** — Bins and Chutes; **Washing Equipment**

Lippmann Engineering Works, Inc.
4603 West Mitchell St., Milwaukee 14, Wis.

Bin Gates; Bins; Classifiers — Sand; **Conveyors** — Flite; **Crushers; Elevators** — Belt, Chain; **Feeders** — Apron, Reciprocating; **Plants; Screens** — Vibrating, Roller; **Washing Equipment**

Ludlow-Saylor Wire Cloth Co.
4333 West Clayton Ave., St. Louis 10, Mo.

Screen Sections — Wire Cloth

Mack Trucks, Inc.
1355 West Front St., Plainfield, N. J.

Tractors — Truck; **Trucks**

Manganese Steel Forge Co.
Richmond St. and Castor Ave., Philadelphia 34, Pa.

Bin Gates; Bins; Grizzlies; Screen Sections; Screens — Vibrating, Shaking, Revolving; **Steel** — Alloy, Carbon, Manganese

Manufacturers Division – National Crushed Stone Association
(continued)

Marion Power Shovel Co.
Division of Universal Marion Corp.
617 West Center St., Marion, Ohio
Dippers — Shovel; **Shovels, Draglines, Cranes, Clamshells**

Marsh, E. F., Engineering Co.
4324 West Clayton Ave., St. Louis 10, Mo.
Bin Gates; Buckets — Elevator; **Conveyors** — Belt, Portable, Steel Apron; **Elevators; Feeders; Plant Design and Layout; Plants**

McKay Co.
1005 Liberty Ave., Pittsburgh 22, Pa.
Welding Equipment and Supplies

McLanahan Corp.
252 Wall St., Hollidaysburg, Pa.
Castings — Iron, Alloy Iron; **Classifiers; Clutches; Crushers, Pulverizers; Elevators; Feeders; Grizzlies** — Roller; **Pillow Blocks; Plants; Screens** — Vibrating, Shaking, Revolving; **Washing Equipment**

Meissner Engineers, Inc.
300 West Washington St., Chicago 6, Ill.
Consulting Engineers; Plant Design and Layout

Mission Manufacturing Co.
P. O. Box 4209, Houston 14, Texas
Bits — Rock; **Drills, Drilling Equipment; Pumps**

Murphy Diesel Co.
5317 West Burnham St., Milwaukee 19, Wis.
Engines — Diesel; **Power Generating and Distributing Systems; Welding Equipment and Supplies**

New Jersey Drilling Co., Inc.
Box 251, Route 206, Netcong, N. J.
Drilling — Contract

Nordberg Manufacturing Co.
3073 South Chase Ave., Milwaukee 1, Wis.
Castings — Manganese, Alloy Steel; **Crushers, Pulverizers; Engines** — Diesel; **Feeders; Grizzlies; Hoists** — Drum; **Power Generating and Distributing Systems; Screens** — Vibrating, Shaking, Revolving

Northern Blower Division
Buell Engineering Co.
6409 Barberton Ave., Cleveland 2, Ohio
Blowers and Fans; Classifiers; Dust Control Equipment — Filter Bag, Electrical Precipitators, Mechanical Cyclone

Northwest Engineering Co.
135 South LaSalle St., Chicago 3, Ill.
Shovels, Draglines, Cranes, Clamshells

Olin Mathieson Chemical Corp.
Energy Division
East Alton, Ill.
Explosives, Blasting Supplies

Pennsylvania Crusher Division
Bath Iron Works Corp.
323 South Matlack St., West Chester, Pa.
Crushers, Pulverizers

Pettibone Mulliken Corp.
4710 West Division St., Chicago 51, Ill.
Buckets — Clamshell, Dragline; **Castings** — Manganese Steel; **Dippers** — Shovel; **Loaders; Pumps**

Pioneer Engineering
Division of Poor & Co., Inc.
3200 Como Ave., Minneapolis 14, Minn.
Asphalt Plants; Bin Gates; Bins; Classifiers; Conveyors — Belt; **Crushers, Pulverizers; Dryers** — Aggregate; **Dust Control Equipment; Elevators; Feeders; Plant Design and Layout; Plants; Screen Sections; Screens** — Vibrating, Shaking, Revolving; **Washing Equipment**

Pit and Quarry Publications, Inc.
431 South Dearborn St., Chicago 5, Ill.
Publications — Trade

REICHdrill Division
Chicago Pneumatic Tool Co.
6 East 44th St., New York 17, N. Y.
Air Compressors; Bits — Rock; **Drills, Drilling Equipment, Supplies; Engines** — Diesel; **Hoists** — Drum; **Hose; Pneumatic Tools; Power Generating and Distributing Systems; Pumps**

Rock Products
79 West Monroe St., Chicago 3, Ill.
Publications — Trade

Manufacturers Division – National Crushed Stone Association
(continued)

Rogers Iron Works Co.
11th and Pearl Sts., Joplin, Mo.
Bins; Castings — Iron; **Classifiers** — Screw, Paddle; **Conveyors** — Belt, Pan; **Crushers, Pulverizers; Drills** — Jumbo; **Drop Balls; Elevators** — Bucket; **Feeders** — Apron, Reciprocating, Belt; **Grizzlies** — Vibrating, Roll; **Hoists** — Mine; **Plants; Screens** — Vibrating, Revolving; **Washing Equipment**

Schramm, Inc.
West Chester, Pa.
Air Compressors; Bits — Rock; **Drills, Drilling Equipment, Supplies; Pneumatic Tools**

Screen Equipment Co., Inc.
40 Anderson Road, Buffalo 25, N. Y.
Screens — Vibrating

Screen Heating Transformers, Inc.
428 Erie St. South, Massillon, Ohio
Electrical Apparatus; Screens — Vibrating, Shaking, Revolving

Simplicity Engineering Co.
Durand, Mich.
Car Shakeouts; Conveyors — Pan; **Feeders** — Vibrating; **Grizzlies; Screen Sections; Screens** — Vibrating

Smith Engineering Works
Division Barber-Greene Co.
P. O. Box 723, Milwaukee 1, Wis.
Belts — Conveyor, Elevator; **Bin Gates; Buckets** — Elevator; **Classifiers** — Sand; **Conveyors** — Belt; **Crushers; Elevators** — Bucket; **Feeders** — Reciprocating, Apron; **Grizzlies; Plant Design and Layout; Plants; Screens** — Vibrating, Revolving; **Washing Equipment**

Spencer Chemical Co.
610 Dwight Bldg., Kansas City 5, Mo.
Explosives, Blasting Supplies

Stedman Foundry & Machine Co., Inc.
P. O. Box 209, Aurora, Ind.
Crushers, Pulverizers — Cage Disintegrators, Hammermills; **Screens** — Vibrating

Sturtevant Mill Co.
103 Clayton St., Dorchester, Boston 22, Mass.
Crushers, Pulverizers; Separators — Air

Taylor-Wharton Co.
Division Harsco Corp.
High Bridge, N. J.
Buckets — Elevator; **Castings; Chains; Conveyors** — Apron; **Dippers** — Shovel; **Drop Balls; Feeders; Screen Sections; Welding Equipment and Supplies**

Thew Shovel Co.
East 28th St. and Fulton Road, Lorain, Ohio
Loaders — Wheel; **Shovels, Draglines, Cranes, Clamshells**

Thor Power Tool Co.
175 North State St., Aurora, Ill.
Belts; Bits — Rock; **Drills, Drilling Equipment, Supplies; Dust Control Equipment; Hoists** — Drum; **Hose; Motors** — Electric; **Pneumatic Tools; Power Generating and Distributing Systems; Pumps**

Timken Roller Bearing Co.
Service-Sales Division
1835 Dueber Ave., S. W., Canton 6, Ohio
Bearings — Tapered Roller; **Bits** — Rock; **Steel** — Alloy

Torrington Co.
Bantam Bearings Division
3702 West Sample St., South Bend 21, Ind.
Bearings

Traylor Engineering & Manufacturing
Division of Fuller Co.
Allentown, Pa.
Air Compressors; Blowers and Fans; Conveyors — Pneumatic; **Crushers, Pulverizers; Dryers** — Aggregate; **Dust Control Equipment; Feeders; Indicators** — Bin Level; **Plant Design and Layout**

Manufacturers Division – National Crushed Stone Association
(continued)

Trojan Powder Co.
17 North Seventh St., Allentown, Pa.
Explosives, Blasting Supplies

Tyler, W. S., Co.
3615 Superior Ave., N. E., Cleveland 14, Ohio
Screen Sections — Wire Cloth; **Screens** — Vibrating, Shaking, Revolving; **Testing Sieves and Sieve Shakers; Vibrators** — Bins and Chutes; **Washing Equipment**

Universal Engineering Corp.
Subsidiary of Pettibone Mulliken Corp.
625 C Ave., N. W., Cedar Rapids, Iowa
Asphalt Plants; Bin Gates; Bins — Portable, Semi-Portable; **Conveyors** — Belt, Pan, Apron; **Crushers, Pulverizers** — Jaw, Roll, Impact, TwinDual Roll, Hammermills; **Elevators** — Bucket, Belt; **Feeders** — Wobbler, Pan, Apron, Vibrating; **Grizzlies; Plant Design and Layout; Plants; Screens** — Vibrating, Shaking, Revolving; **Washing Equipment**

Varel Manufacturing Co.
9230 Denton Drive, Dallas 20, Texas
Bits — Rock

Vibra-Tech Engineers, Inc.
407 Hazleton National Bank Bldg., Hazleton, Pa.
Seismological Instruments, Surveys

Vibration Measurement Engineers, Inc.
725 Oakton St., Evanston, Ill.
Seismological Instruments, Surveys

Webb, Jervis B., Co.
8951 Alpine Ave., Detroit 4, Mich.
Chains; Conveyors — Belt, Apron, Drag, Flight; **Elevators** — Bucket; **Feeders; Plant Design and Layout; Plants**

Werco Steel Co.
2151 East 83rd St., Chicago 17, Ill.
Buckets — Clamshell, Dragline, Elevator; **Castings** — Manganese, Alloy Steel; **Chains; Conveyors** — Belt; **Crushers, Pulverizers; Dippers**—Shovel; **Drop Balls; Screen Sections; Wire Rope and Related Products**

Western-Knapp Engineering Co.
30 Rockefeller Plaza, New York 20, N. Y.
Consulting Engineers

White Motor Co.
842 East 79th St., Cleveland 1, Ohio
Batteries; Engines — Gasoline; **Power Generating and Distributing Systems; Tractors** — Truck; **Trucks, Trailers, Truck Bodies**

White Motor Co.
Autocar Division
Exton, Pa.
Trucks, Trailers, Truck Bodies

Wickwire Spencer Steel Division
Colorado Fuel & Iron Corp.
575 Madison Ave., New York 22, N. Y.
Screen Sections — Wire Cloth; **Screens** — Vibrating, Shaking, Revolving; **Wire Rope and Related Products**

Williams Patent Crusher & Pulverizer Co.
2701-2723 North Broadway, St. Louis 6, Mo.
Bins; Classifiers; Crushers, Pulverizers; Feeders; Screens — Vibrating; **Separators** — Air

Wiss & Associates
Division of Engineers Collaborative
570 Northwest Highway, Des Plaines, Ill.
Seismological Instruments, Surveys